ON FRACTURED GROUNDS: THE ECONOMIC VIABILITY OF PLANNING AS A LOCAL REGULATORY TOOL FOR HYDRAULIC FRACTURING

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ABSTRACT

As states trend towards a legal hegemony on hydraulic fracturing regulations, municipalities are pushing back through the use of zoning codes and setbacks to curtail the proliferation of oil and gas wells. This study looks at the viability of zoning setbacks as a tool to foster better social and environmental outcomes for regions with grappling with the encroachment of fracking near public drinking water sources, and examines the shifts in regulatory frameworks that may or may not have led to unchecked geospatial distribution of unconventional wells. Moreover, this study uses econometric and shift share analysis to evaluate existing claims of income and employment benefits touted by proponents of increased fracking activity for decreased municipal oversight, focusing specifically on Texas and Pennsylvania. The results of the study point towards a lack of significant impact of an increase in well frequency and well density on median incomes and employment, and that setbacks up to 1 mile from groundwater sources would not significantly diminish extraction rights in Texas or Pennsylvania.

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I. INTRODUCTION

The oil crisis of the 1970's led major oil importing countries including the United States of America to scramble under petroleum shortages due to supply disruptions in the Middle East as a result of the Yom Kippur War of 1973 and the Iranian Revolution of 1979 . The resulting aftermath saw a global heightened awareness on the issue of energy and national security; while countries that lacked oil reserves such as Germany and Japan poured investment into alternative energy research, other countries such as the US doubled down on maintaining high volumes of oil reserves to hedge against the risk of oil being utilized as an economic weapon once more (Yergin, 2009). This goal of US energy independence was realized in November 2019, when America became a net exporter of all oil products. Historical analysis of US oil imports show that the "barrels per day" import of crude oil and petroleum products peaked in 2006, then fell precipitously[1]. A significant factor in the success of US energy independence can be attributed directly to improvement on hydraulic fracturing technology which allows "tight oil", oil which would be inaccessible through conventional extraction methods, to be extracted (Mills, 2008). However, recent increase in fracking activity as well as volatility in energy markets have propelled hydraulic fracturing once again to the spotlight of even US presidential debates[2], as state legislatures debate the merits of giving or consolidating fracking regulatory powers to or from local municipalities where fracking occurs.

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[1] Energy Information Administration. "4-Week Avg U.S. Net Imports of Crude Oil and Petroleum Products". Retrieved December 1, 2019.

[2] Parti, Tarini. "Biden Aims for Tricky Balance on Fracking." *Wall Street Journal*, March 16, 2020, sec. Politics. https://www.wsj.com/articles/biden-aims-for-tricky-balance-on-fracking-11584396925.

The expansion of hydraulic fracturing technology allowed for more plays of America's shale areas, promoting growth of economic activity in previously untapped local towns; however, such rapid proliferation of drilling areas have pitted local regulatory powers against state regulations in areas where the public majority are not in agreement with hydraulic fracturing processes. The intersection of planning and oil activities have become only more intertwined in the past several decades, with individual states' economic interests in oil and resource extraction often clashing with the desire of local communities. While planning and zoning is often reserved to the discretion of localities, states have tried to wrestle regulatory power away from local municipalities on the issue of natural resource extraction regulations (Negro, 2012). This is especially true when the planning tools such as zoning are employed to greatly restrict land use and development in areas where much of the value of the property is derived from the ability to extract what lies underneath it. Certain zoning regulations and regulations intended to restrict where oil and gas can be extracted have become an issue of legal contention, such as in Colorado where local residential zoning mandates have run afoul of oil industry interests by attempting to extend drilling setbacks further from residential zones (Dawid, 2018). Due to a lack of uniform federal guidance on a standard boundary between hydraulic fracturing activities in residential or commercial hubs, extractions can take place within close proximity to homes, shopping centers, schools, and public drinking wells in certain locales.

The US Chamber of Commerce has released several statements about their support for oil extraction and hydraulic fracturing as necessary to the economic health of the country, a sentiment that resonates throughout various federal agencies. The rhetoric thus far over represents the extremes of both the proponents of hydraulic fracturing and the advocates for a total ban against it; this manifests itself in cases such as Texas, where hydraulic fracking is welcome at both the state and local levels, in contrast to France, where public outcry against fracking as resulted in a complete moratorium [3] against unconventional extraction methods. Research is lacking in an in-depth analysis of a graduated approach to zoning and fracking; the costs and benefits of the impacts of varying levels of zoning regulations have, to date, not been analyzed through a socio-economic lens enough to verify the true impacts of curtailing hydraulic fracturing activities. The aim of this research is to reconcile conflicting reports on the economic costs and benefits of increased hydraulic fracking regulation, and see if measurable impacts can be observed from using uniform zoning setbacks as a tool for municipalities to self regulate in the absence of clear state or federal oversight. While the economics of stricter regulations on fracking are inherently significant in policy decisions, the social issues raised by fracking should not be overlooked, particularly in the areas of environmental justice and equitable distribution of the negative externalities imposed by fracking. Air pollution and water contamination are only some of the issues facing communities disproportionately impacted by the effects of the US shale boom; at a higher level, this research aims to uncover some of the underlying struggles for regulatory control of fracking, and the how the battle of wills may or may not impact which counties the social costs are most acutely felt.

[3] (LOI n° 2011-835 du 13 juillet 2011 visant à interdire l'exploration et l'exploitation des mines d'hydrocarbures liquides ou gazeux par fracturation hydraulique et à abroger les permis exclusifs de recherches comportant des projets ayant recours à cette technique, 2011)

II. DEFINITIONS & BACKGROUND

Hydraulic fracturing as defined by the US Chamber of Commerce is vertical oil drilling and extraction technique by which vertical wells perpendicular to oil or gas formation are stimulated via a cocktail of water, sand, and chemicals under pressure, often referred to as "fracking fluid". This technique is most commonly used on rocky earth layers of low-permeability, usually made of shale or sandstone (US Geological Survey, n.d.). For the purposes of this study, "fracking", and "unconventional drilling" all refer to the process of hydraulic fracturing,

Fracking fluids usually contain volatile organic compounds (VOC) and improper disposal of fracking fluids or technique can cause VOCs to escape to the surface level. In addition to VOCs, the stimulation technique itself requires water to be drawn from existing ground or surface water, and can range anywhere from 1.5 million gallons to 16 million gallons depending on the well (Gallegos, Varela, Haines, & Engle, 2015). Such extensive use of groundwater sources can be a point of contention in localities where water is scarce and hydraulic fracking further exacerbates stresses on public water consumption.

Advocates against hydraulic fracturing have argued that the process risks harming localities environmentally and in public health: ground and surface water contamination, air pollution, induced earthquakes, methane leakage, as well as impacting noise, and disrupting life in residential areas are all potential risks of hydraulic fracturing (Brown, 2007). There traditionally exists little federal oversight on industry fracking and drilling practices, as fracking standards are not regulated by the US Environmental Protection Agency; federal land managers such as the US Bureau of Land Management (BLM), the US Forest Service (USFS), and the US Fish and Wildlife Service (USFWS) all share in some oversight, but only in their respective federal lands (US Geological Survey, n.d.). Furthermore, fracking fluids used in hydraulic fracturing were specifically excluded from protections in the Clean Air Act, Clean Water Act, Safe Drinking Water Act through the 2005 Energy Policy Act (Kosnik, 2007). In general, the regulatory powers curtailing or permitting oil and gas exploration activities are deferred to the state level, which then may or may not be remitted to the local and municipal level. While the EPA have repeatedly restated that hydraulic fracturing conducted by permitted companies do not pose significant environmental risk to surrounding communities[4], past cases have occurred where seepage of fracking fluids have leaked into drinking wells, as was the case in Clark County, Wyoming in 2007 (Brown, 2007). In a 2013 review, 31 states had minimum setbacks in place, ranging from 100ft (New York) to 1000ft (Maryland)[5] but no updated review exists, and New York, among several other states, have since imposed full bans on fracking. While no standard guideline exist as a recommended minimal setback distance for oil and gas drilling, previous studies have indicated that a setback of 600ft from residences is adequate for preserving air quality and public health[6], and some states, such as Colorado, have adopted setbacks of 350ft to 1000ft, depending on building type[7]. The issue of how much setback distance is appropriate is hotly contested as more state legislatures consider adopting bills that expand setback distance; more recently, California has considered a 2,500ft setback on unconventional oil and gas wells from public facilities, dwellings, and schools. Colorado's State Department of Public Health and Environment have reported that adverse effects from the chemicals

[4] The EPA has since amended their previous evaulation of "no evidence of widespread, systemic impacts" of hydraulic fracturing on drinking water source to "evidence that activities in hydraulic fracturing water cycle can impact drinking water resources under some circumstance" (US EPA, 2013)

[5] EHN. "Fracking in Pennsylvania Is Too Close to Residents for Safety: Study," August 23, 2018. https://www.ehn.org/pennsylvania-fracking-too-close-to-homes-2598167729.html.

[6] "Air Quality Study | City of Fort Worth, Texas." Accessed March 22, 2020. http://fortworthtexas.gov/gaswells/air-quality-study/.

[7] "600 Series Colorado Oil and Gas Safety Regulations". Accessed April 4, 2020. https://cogcc.state.co.us/documents/reg/Rules/LATEST/600Series.pdf

used in drilling could cause health problems for people as far as 2000ft away[8]. Furthermore, a separate study by the Environmental Health Project, a nonprofit in Southwest Pennsylvania, which found that 89% of a panel of environmental and public health experts agree that a minimum setback of 1 mile to 1.25 mile between unconventional wells and human activity is appropriate[9]. Because what can be considered as an appropriate minimum setback distance can vary from state to state, this study examines various setbacks ranging from 100ft to 2miles.

Prior research in this area has been divided between legal policy analysts, environmental scientists, and economists. This research seeks to bridge the gap between these fields by posing the question of oil, policy, and economy as one that sits at the heart of urban planning. As such, the research questions are focused on quantitative and data-driven outcomes not only limited to commodity markets and state economic performance, but also on the public social outcomes. More than simply affirming or refuting the costs and benefits of increased regulation on hydraulic fracturing alone, this research seeks to bring attention to the necessity of factoring public social goods such as access to clean drinking water as part of the policy making evaluation framework. While urban planning also traditionally rooted itself in the realm of public interest, this research hopes to highlight the extent to which tools like zoning have measurable impact on quantifiable economic social benefits and costs beyond curtailing nuisances.

[8] *Reuters*. 2020. "Anti-Fracking Group Proposes Limiting Colorado Oil and Gas Drilling," January 7, 2020. https://www.reuters.com/article/us-usa-oil-colorado-idUSKBN1Z627I.

[9] Wong, Nicole J. n.d. "Existing Scientific Literature on Setback Distances from Oil and Gas Development Sites," 9.

III. LITERATURE REVIEW

A preliminary literature review reveals that while significant research has been done on hydraulic fracturing and resource extraction activities in each of the respective fields of economics, public health, environmental regulation, and land use law, there does not exist a uniform body of research that connects the distinct fields cohesively. The segmentation of literature represents itself as both a boon and a bane, as the large body of research on hydraulic fracturing as a whole allows for virtually a combination of topics to be examined, but a lack of intermediate linkages makes any in depth analysis difficult. For example, there exists a great body of literature on the different flavors of land use regulations across states restricting hydraulic fracturing, but such literature does not allude to the economic effects of such restrictions beyond loss of potential property value of the landowner. Similarly, the environmental effects of hydraulic fracturing are well explored and contended against by conflicting sources, but the economic impacts of such environmental harms are not explored. In the realm of economics, most literature looks only at market indicators of oil price movements as a function of oil reserves, global supply, and oil price volatility, with most choosing to focus on the temporal effects of oil industries on local economies.

In part, this literature review is intended to investigate the extent of interconnectivity between the three academic disciplines: economics, urban planning and public policy, and environmental science. The review will also inform the variables used in the predictive economic models, and define regression constraints. The preliminary review will be organized thematically in accordance to the three aforementioned fields.

Economic Impacts

In 2016, the US Chamber of Commerce, in partnership with the Global Energy Institute (a subsidiary of the CoC) released a report titled "What If Hydraulic Fracking Was Banned?", which juxtaposed a future in which all hydraulic fracturing activities stopped against a future where there was no change to the existing schema (termed "Business as Usual" or BAU). Using data from four states, Texas, Pennslyvannia, Colorado, and Ohio, their economic projections showed a staggering tripling of crude oil prices over six years and a doubling of electricity prices by 2022. Other economic indicators projected within the report include oil and gas sector jobs lost, total US jobs lost, GDP lost, and total US household income lost as a result of a hydraulic fracturing ban. This report was supplemented by a new report released in 2019 titled "The Economic Benefits of Hydraulic Fracturing to New Mexico - And the Consequences of a Potential Ban," which updated the 2016 report numbers while simultaneously touting the contributions to government revenue and public service by the energy industry. However, the methodology used in the generation of these models relied on an "input-output" model[10] which does not account for factors such as the impact of more efficient clean energy technology, shift in energy consumption preferences, and climate change.

GDP has traditionally been used to measure economic activity, not economic well-being; it seeks to provide answers to the speed at which the economy is growing, but cannot express the national welfare of the country (Costanza, Hart, Posner, & Talberth, 2009.). Excluded from GDP measurements are activities such as volunteerism, capital infrastructure investment, change in natural resource reserves, and changes in public social costs, all vital nonmarket goods. Furthermore, there exists a consensus in the literature within the social sciences of the inability of GDP to be a

[10] IMPLAN model was used in both the 2016 and 2019 reports by GEI

comprehensive indicator of changes in social investments such as public health (Fan, Bloom, Ogbuoji, Prettner, & Yamey, 2018). Though no specific literature exists on the applicability of GDP as a measure of public welfare in an environmental capacity, we can assume that a significant change in GDP indicates some level of change in economic activity (Dynan & Sheiner, 2018). Whether or not a negative change in GDP is necessarily a negative indicator of economic welfare is still up for debate.

Economic analysis of unconventional gas and oil development is mostly centered on the economic policy effects of energy boom/bust cycles in smaller communities by comparing historical oil and gas price fluctuations with employment trends (Kelsey, T.Wm Partridge, M.D., & White, 2016.) Most policy recommendations from such papers underscore a need for governments to reinvest revenues from drilling activity back into community infrastructure and economic diversification. This is done in order to hedge against the costs of post-extraction drops in economic activity as case studies have shown that preparation for "post-oil industry era" is critical to supporting urban economies in the long run, as is the case in rural towns with low economic activity before the presence of oil industries (Tarigan, A.K.M., Samsura, D.A.A., Sagala, S., & Wimbardana, R. 2017). Because this research topic is focused on the short term effects of ongoing fracking activities and not post-extraction cases, the literature is only tangentially related. However, the literature reviewed remains good reference to areas of economic development touched by the oil industry. In an article by Leslie Jacques[11], the validity of job creation claims by fracking proponents are questioned, where discrepancy lies in the number of jobs that the US government touts a new oil or gas pipeline would create, and numbers estimated by independent institutions. Jacques also points to renewable energy advocates that also laud the clean energy sector job creation potential, underscoring the fact that the

[11] Leslie, Jacques. 2018. "Opinion | Do Pipelines Really Create Lots of Jobs?" *The New York Times*, May 10, 2018, sec. Opinion. https://www.nytimes.com/2018/05/10/opinion/environment-pipelines-jobs-carbon.html.

two sectors are in some way in direct competition with one another. That said, whatever losses in employment experienced by declines in the oil and gas industry would not necessarily be captured by the renewable energy sector, since the skills and specializations of the two industry workforces differ. Jacque states that the "right way to assess" energy projects is through a cost-benefit analysis of the social costs of projects, on issues such as carbon emission, other forms of air pollution, and impact on climate change.

In a paper by Timothy Fitzgerald titled "Frackonomics"[12], the financial considerations of profitable hydraulic fracturing are laid out. In terms of maximizing profit, the paper states that well operators can opt to either increase the output of wells through increasing area of contact with the shale reservoir, or by simply drilling more holes. This makes the basis of this paper's emphasis for looking at net well counts across counties rather than volume of output, especially since it is stated that the process of drilling more wellbores is significantly more expensive to do, dampening industry claims that regulatory constraints will decrease profitability by decreasing total well count potential. The closest study in terms of scope to this research would be a study on the income and employment effects of fracking in the Marcellus shale region (where Pennsylvania is) by Paredes, Komarek, and Loveridge, which found no statistically significant income or employment effect by increased fracking, and that little incentive exists to incur the costs associated with fracking. The stakeholders that stand to lose from increased restrictions on fracking besides well operators are the landowners who lease land to oil and gas industries, and state governments that depend on tax revenue from fracking. A monthly labor review report by the US Bureau of Labor statistics[13] in August 2018 quantified wage gains from

[12] Fitzgerald, Timothy. n.d. "Frackonomics: Some Economics of Hydraulic Fracturing." *Case Western Reserve Law Review* 63 (4): 28.
[13] Pickenpaugh, Gavin C., and Justin M. Adder. 2018. "Shale Gas Production and Labor Market Trends in the U.S. Marcellus–Utica Region over the Last Decade." *Monthly Labor Review*, 1–20.

2007-2016 as an overall all-industry increase of 75 in the Marcellus -Utica region, but the figure was inclusive of additional compensation such as stock options and bonuses, which are generally not available to the main body of construction and maintenance crews that operate the wells. Furthermore, looking at Pennsylvania specifically, the report indicated a decrease in industry employment for that period despite an increase in total wells.

Generally speaking, the literature that supports fracking tends to be in the form of flashy business reports and government memos that are generally encouraging of increased potential windfalls from expansion in the oil and gas sector while independent and academic research tend to point to no significant economic benefits that would outweigh the social costs. Both perspectives help this study position itself in the center as well, where the question is not directed towards the existence of economic benefits, but the degree to which fracking is beneficial.

Regulatory Framework and Planning

The existing regulatory frameworks for oil and gas drilling activity have been extensively documented and analysis (Negro, 2012), providing a solid basis for this research, especially as the economic studies fail to be directly related to the research questions, and too much variability exists in the environmental and public health studies. We can understand the rise of drilling activity in the United States as a persistent clash between corporate and private interests which in certain cases, such as in Los Angeles, ultimately merged (Elkind, 2012). Traditionally, states have been separated as either falling under “Dillon's Rule” or “Home Rule”, with distinction being that the former allows for local authority over matters only when the state law expressly grants it power while “Home Rule” states generally defer local governments the ability to manage their own affairs as long as municipal regulations do not run afoul of state interests (Russell & Bostrom, 2016). Certain states are ambiguous or limited in their powers are home rule states. Of the four states to be analyzed in this research question, Ohio, and Colorado are strictly home rule states while Pennsylvania has some form of both, and Texas refers generally to Dillion's Rule with the exception that cities may adopt home rule if the total population exceeds 5,000 (Texas Constitution, Article XI, Section 5). Regardless of the state, planning and zoning powers have long been delegated as squarely within the realm of accepted municipal regulation. However, in the case of Pennsylvania, the state has explicitly reserved sole determination of any oil industry related activity.

The brunt of policy decisions affecting oil and gas industries in most cases fall to the state level, where the level of regulation is dependent on the geography and prevailing industries of the area. In most cases, the private interests that lobby for expansion of fracking rights prefer state rule over federal rule, particularly because the absence of overarching federal oversight creates opportunities for variable leeways in state laws (Warner and Shapiro 2013). However, in many cases, the regulatory guidelines of the state may only control production, delivery, and transportation, whereas the question of where an oil or gas company may source their product is dependent on municipal zoning ordinances. Due to growing tensions and with the prodding of the energy industries, states have begun to consider reclaiming regulatory land rights for drilling (Negro, 2012).

The likelihood of lax or strict regulatory constraints on fracking might be defined by a municipality's geographic proximity to sedimentary basins and shale regions, the political affiliation of its voter base, existing number o f number of oil and gas wells, and well presences in drinking-water watershed (Choma, Hanoch, and Currie 2016) (Bird, Heintzelman, and Walsh 2014). The same study by Bird et al. looked at modeling the significant indicators of what would cause bans or moratoriums on fracking using New York as a model, where localities were free to make their own regulatory restrictions on fracking prior to the statewide ban on fracking in 2014. That study utilized a Getis Ord Gi* hotspot approach to find clustering in bans; this study also endeavors to use the same technique, but applied to unconventional wells as a proxy for fracking policy in the absence of well documented data New York has. A more comprehensive investigation of existing regulatory conditions surrounding the key states for this study will be delved into in the findings sections.

Environmental and Public Health

Environmental studies between hydraulic fracturing activity are extremely specific in their scopes, and research is conducted on a case by case basis. This study will not focus on the environmental impacts of fracking, as that is well documented by environmental scientists and health industry professionals. Instead, the body of literature on environment and public health acts as an informative background to base what social costs are at stake in considering policies on fracking.

Hydraulic fracking is seen as both an indispensable tool to be exploited in order to sustain a low carbon economy in order to reduce reliance on coal while also castigated by opponents as a short term energy solution as best (Watterson & Dinan, 2018). The purported environmental and public health impacts of hydraulic fracturing have promoted states such as New York to impose a moratorium on hydraulic fracturing activities (Kaplan, 2014) as well as in parts of Europe. The federal government's stance on the safety and benefits of hydraulic fracturing is reiterated across multiple federal agency sites (EPA, USGS, EIB, GEI, etc). An EPA study on the impacts of hydraulic fracturing on drinking water examined the link between fracking and water acquisition for fracking fluids, chemical mixing of fracking fluid, well injection, and waste disposal; its conclusion was that while some evidence of negative impacts exist and may be exacerbated by certain conditions, the true extent of the impacts cannot be adequately assessed due to gaps in data (U.S. EPA, 2016). Though the literature review has shown a consistent trend of verifiable environmental and public health impacts of fracking on communities (Brown, 2007), the scale of such impacts are varied depending on the report. Even the spatial variability of water use in hydraulic fracturing is under contention (Gallegos, T. J., Varela, B. A., Haines, S. S., & Engle, M. A., 2015) due to the differences in fracked oil conditions.

In terms of fracking activity and public health beyond isolated case studies (Brown, 2007), certain studies have examined the relationship between petroleum and health care, where the supply shifts in petroleum production is argued to have a measurable disruptive impact on health care sector(Hess, Bednarz, Bae, & Pierce, 2011). However, the scope of the research is limited to an analysis on petroleum supply's effect on health care market goods and not on the social cost of public health arising from any secondary environmental effects of petroleum production. A 2010 report on the results of a cost benefit analysis on the social costs and social benefits of biofuels is the closest in terms of relevant methodology in the area of energy impacts, oil, and social costs (de Gorter & Just, 2010). The study looks at the effect on CO2 emissions and externalities as a function of biofuel consumption mandates and tax credits, but provides a clear structure on conducting cost-benefit analysis within the energy sector. More closely related to this research topic is existing research on shale gas supply on climate change policies; such topics involve a valuation on energy security and prices (Victor, Nichols, & Balash, 2014), but provides a demonstrative link between shale extraction activity and interest in climate change and energy security, though most conclude that such linkages have failed to produce long term decrease in CO2 emissions. Moreover, other studies at the intersection of energy and urban planning have argued for the significance of urban planning in curtailing nonrenewable energy resources to allow for innovation in clean energy production (Pucar, 2015).

No quantitative assessment exists of hydraulic well density and environmental risk, but a near analysis was previously done on 2014 fracked well data to analyze the number of fracked wells in the US that are within a 2km radius of groundwater drinking well (Jasechko & Perrone, 2017). The study found that over 37% of wells were within 2km of public drinking wells, which equates to roughly 1.24 mile radius. It would be reasonable to conclude from this study that the 2 mile radius buffer to be used in this research question might effectively act as a total ban on hydraulic fracturing.

IV. RESEARCH DESIGN

This thesis centers its design and methodologies around whether or not local municipalities can use planning as a tool to balance the economic benefits of oil and gas extraction with the social and public health risks of hydraulic fracturing. Three key questions are addressed:

1. What is the existing geospatial distribution of unconventional oil and gas wells with respect to groundwater sources?
2. Do existing drilling codes create equitable social distribution of unconventional wells?
3. Would the regulation of fracking activity severely inhibit local industries and employment?

The answers to these three research questions would allow for a more transparent reframing on the contentious and politically fraught topic of hydraulic fracturing as proponents from both sides look towards the federal government or state legislators for top-down decisions on fracking while punting local laws to the wayside. By evaluating whether or not there is a space for planning tools in the question of fracking, municipalities can be empowered to regain a stake in the discussion.

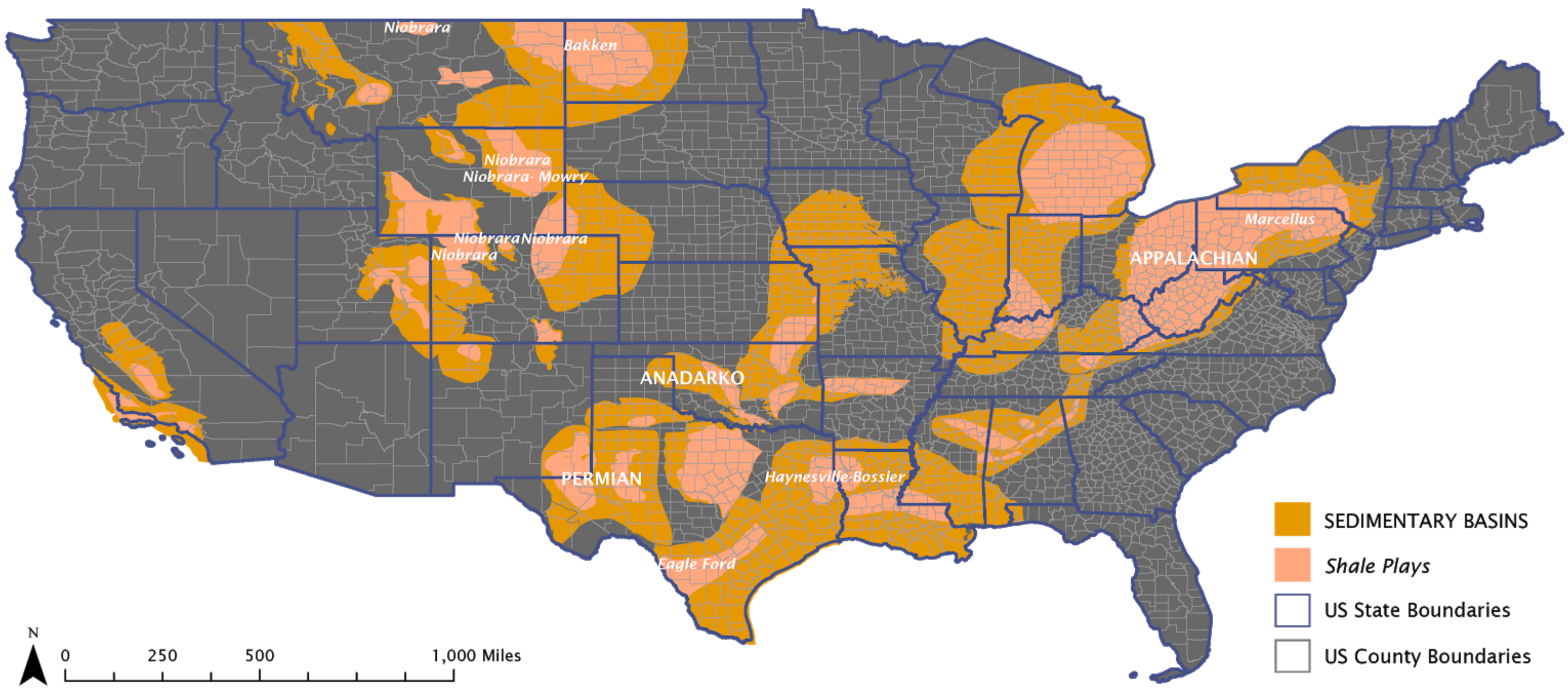
Study Area

Geographic Bounds

The study area looks at Texas and Pennsylvania for the research of possible socioeconomic or geospatial patterns in unconventional well development. Data is aggregated at the state county level, which allows for cross referencing of regression results with local regulations and municipal planning requirements, which would be harder to discern at the more granular census block or tract level. Though some spatial analysis has been done at the state level for the United States as a whole, the availability of uniform datasets such as hydrology and groundwater shapefiles varies too considerably from state to state to do a comprehensive study in the geospatial distribution of unconventional wells for every state. Texas and Pennsylvania were selected as two states on top of large shale basins with enough recorded unconventional well data for analysis. The two states also differ considerably in their approach to fracking regulation and local methods of control, allowing for comparative analysis of their respective public policy outcomes. All 67 counties in Pennsylvania and all 53 counties in Texas were examined.

A preliminary data analysis was done on all US counties with "fracking potential", defined as counties that lie directly on top of US sedimentary basins that hold oil and gas resources. Furthermore, a cursory examination using counties that had existing shale plays was also done, but not used as a basis for forming conclusions due to the transient nature of existing shale plays, which are dependent on a combination of state regulations, technological advances, and the market conditions of the oil and gas industry both domestically and internationally.

FIGURE 1
Map of Major US Shale and Sedimentary Basins



Data: EIA, U.S. Geological Survey Sedimentary Basins

Shift share analysis includes Illinois, which legalized fracking in 2013 under the Illinois Hydraulic Fracturing Regulatory Act to act as a control for the effects of formal legalization of hydraulic fracturing, and New York, which banned fracking in 2014 to act as a control for the effects of formal bans on hydraulic fracturing. Figure 1 shows that all four states touch or are on top of major shale basins and have potential for inducing major shale plays. A larger regression was done in all states in America that had at least one recorded unconventional well permit, but onlyTexas and Pennsylvania were included in the groundwater-hydraulically fractured well distance analysis.

Temporal Bounds

While hydraulic fracking to extract natural resources was prevalent in Texas since the 1990's, no formal fracking ban was proposed within Texas until 2014, when the City of Denton proposed and passed a ballot initiative to restrict hydraulic fracturing inside city limits[14], which was subsequently repealed and state legislation enacted in 2015 to curtail local municipal power by making local fracking bans illegal[15]. Pennsylvania first regulated oil and gas drilling in 1984, establishing guidelines and regulatory frameworks under the oversight of the Pennsylvania Department of Environmental Protection (DEP).[16] Further legislation was passed 2012, adopting the Oil and Gas Act of 2012 (Act 13) which imposed impact fees on unconventional drilling activity[17]. Further moratoriums were imposed on fracking activities in certain state parks and forested lands in 2015, a reinstatement of a "de facto moratorium"[18] from a 2010 initiative by the Delaware River Basin Commission (DRBC), a federal interstate compact commission with authority over water basins in parts of Pennsylvania. Given the constantly fluctuating nature of legislations and the availability of sociodemographic ACS data, two time periods are used as spot analysis dates: 2012 and 2017.

[14] Ballotpedia. "Historical Texas Fracking Information." Accessed March 15, 2020. https://ballotpedia.org/Historical_Texas_fracking_information.
[15] NPR.org. "New Texas Law Makes Local Fracking Bans Illegal." Accessed March 15, 2020. https://www.npr.org/2015/05/20/408156948/new-texas-law-makes-local-fracking-bans-illegal.
[16] "Pennsylvania | Shale & Fracking Tracker | Vinson & Elkins LLP." Accessed March 15, 2020. https://www.velaw.com/shale-fracking-tracker/resources/pennsylvania/.
[17] "PUC - Act 13 (Impact Fee)." Accessed March 15, 2020. http://www.puc.state.pa.us/filing_resources/issues_laws_regulations/act_13_impact_fee_.aspx.
[18] "Pennsylvania | Shale & Fracking Tracker | Vinson & Elkins LLP."

Methodology

Several analyses were done for the purpose of this study, starting with a larger look at the relationship between total number of unconventional wells per county, and economic indicators such as employment and median income. While more recent studies on the economic impacts of hydraulic fracturing bans have all generally relied on Input-Output (I/O) models such as REMI or IMPLAN (Hassett and Mathur 2013)(IHS Global Insights 2013)(Wobbekind and Lewandowski 2014)(US Chamber of Commerce 2016)(US Global Energy Institute 2020), the proprietary nature of these models and lack of transparency in multipliers used make replication and verification of output results difficult[19]. Even within bount of previous studies using I/O models, the aggregate effects of a fracking ban have produced widely differing numbers in projected employment, GDP, and energy prices over a 25 year time period[20], highlighting a lack of uniformity in initial input assumptions and variability in individual multipliers based on the model used. Furthermore, studies on the limited applicability and accuracy[21] of Input-Output models (Rosenbluth 1968) to economic and regional analysis of effects beyond tax, GDP, and production of goods and services (Leontief 1955) falls calls into questions the degree to which output results from such models can predict changes over an extended period of time.

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[19] Metadata Documentation on usage of IMPLAN model
https://unfccc.int/files/adaptation/methodologies_for/vulnerability_and_adaptation/application/pdf/economic_models_-_input-output_modeling__with_implan_.pdf
"Input-output accounting (using the IMPLAN model as an example) describes commodity flows from producers to intermediate and final consumers. The total industry purchases of commodities, services, employment compensation, value added, and imports are equal to the value of the commodities produced. Industries producing goods and services for final use and purchases for final use (final demand) drive the model. Industries producing goods and services for final demand purchase goods and services from other producers. These other producers, in turn, purchase goods and services. This buying of goods and services continues until leakages from the region stop the cycle. The resulting sets of multipliers describe the change of output for every regional industry caused by a US$1.00 change in final demand for any given industry. "

[20] ibid

[21] Conference on Research in Income and Wealth. *Input-Output Analysis, an Appraisal a Report of the National Bureau of Economic Research, New York.* Princeton: Princeton University Press, 1955.
http://books.google.com/books?id=MHURAQAAMAAJ.

The original use cases detailed by Wasilly Leontief for I/O models were based on a broad conceptualization of economic analysis as holistic accounting system[22] under a competitive free market. This generalization of economic interdependencies allows for a snapshot view of structural changes in the economy as a result of changes in fiscal or public policy, but should not be relied upon as definitive predictions of market outcomes in the long run. Because the Input-Output models only account for multipliers on demand and supply for known existing industries at the time of analysis[23], the results fail to account for shifts in industrial capacities or technological innovation over time. In the case of oil and natural gas, this includes failures to account for changes in demand and price effects of renewable energies, electric vehicles, and proliferation of alternative fuels and energy sources as the saliency of climate change comes to the forefront of discussions within the energy sector and global markets. Furthermore, previous studies have also questioned the appropriateness of relying on traditional methods of computing localized multiplier effect (Paredes, Komarek, and Loveridge 2015) on assessing what should be an econometric approach to estimating income and employment impacts.

While I/O models are a great tool for rapid assessments of industrial dependencies and market resiliency to policy changes, it presupposes answers to questions asked regarding the degree of impact a policy towards an industry will have through its multipliers. The purpose of this study is precisely to question if the multipliers used in previous studies of hydraulic fracturing regulation adequately reflect the relationship between the ability to drill wells and socioeconomic indicators of a region.

Near Analysis

[22] ibid
[23] ibid.

The first question research questions centers on the geospatial distribution of existing unconventional wells and its spatial relationship with groundwater sources and public drinking wells. Using counties from Texas and Pennsylvania as subjects of the study, a Getis-Ord Gi* Hotspot analysis was conducted to highlight significant clusters of unconventional wells, and acted as a cross reference point when well data was aggregated to the county levels and reclassified by quantiles, since a higher number of wells within a county alone does not necessarily mean that a statistically significant cluster exists within that county. In order to classify as a statistically significant hotspot, the county must contain a high number of unconventional well relative to other counties, and be surrounded by counties with comparably high well counts as well[24] while the inverse is true for statistically significant clusters of cold spots. A series of buffers were created for each public water source to find the total number of wells that would become defunct should well locations be regulated by zoning setbacks.

TABLE 1

Zoning Buffer Distances

Feet	100	1320	2640	5280	10560
Miles	0.019	0.25	0.5	1	2
Equivalent	Minimum distance between septic tanks and water wells	5-minute walk	The horizontal width of Central Park from East to West	1 minute drive on a 60mph freeway	The length of the National Mall from the Capitol Building to the Lincoln Memorial

Near analysis is then done in arcGIS to calculated the distances in feet of the nearest public well or groundwater well for each hydraulically fractured well point, assuming that the diameter of

[24] "How Hot Spot Analysis (Getis-Ord Gi*) Works—ArcGIS Pro | Documentation." Accessed March 24, 2020. https://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/h-how-hot-spot-analysis-getis-ord-gi-spatial-stati.htm.

each well is more or less negligible in the calculation[25]. The average nearest distance of the fracked well to public drinking water source was then calculated by spatially joining fracked wells to counties and the average computed per county. The output dataset was then used in the analysis of the second research question, which aims to find if densely clustered wells or wells with closer proximity to public water sources were more likely to be in neighborhoods characterized by certain income levels or communities with high proportions of certain ethnicities.

FIGURE 2
Getis-Ord Statistic Calculation

The Getis-Ord local statistic is given as:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{\left[n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j} \right)^2 \right]}{n-1}}} \qquad (1)$$

where x_j is the attribute value for feature j, $w_{i,j}$ is the spatial weight between feature i and j, n is equal to the total number of features and:

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n} \qquad (2)$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2} \qquad (3)$$

The G_i^* statistic is a z-score so no further calculations are required.

Source: ESRI, ArcGIS

Linear and logistic regression models were used to find the primary determinants of well concentration; because the relationship between wells and local economic effects were unknown, with many studies drawing causal relationship between the number of wells with local economy, and others denying such direct relationships, this study endeavors to model the relationship between

[25] Oil wells range anywhere from 5in to 1 meter in diameter, while drinking wells average 6 inches

sociodemographic indicators and fracking activity as measured by the density of hydraulically fractured wells in wells per acre.

For the purposes of this study, only in fracked wells Texas will be analyzed in the context of drinking well proximity and fracking density for this report, due to the availability of specifically public drinking well data that allows for a more meaningful interpretation of outcomes[26]. Social influences on well density and iterations of variables where some were log transformed to normalize the distribution are as follows:

EQ 1: $Wd = \beta_0 + \beta_1\, log(N) + \beta_2\, log(D) + \beta_3\, log(I) + \beta_4 T$

EQ 1.2: $Wd = \beta_0 + \beta_1\, log(N) + \beta_2\, log(D) + \beta_3\, log(I) + \beta_4\, log(T)$

Where:

Wd = (Well density) Hydraulically fractured wells per acre per County

N = Percentage of Population that identifies as a race other than “White” per County

D = Population Density (people per acre)

I = Median Income per County

T = Percent of voters who voted for the Republican Candidate in 2016 Presidential Election per County

Because well density for some counties without any unconventional wells equaled 0, the log of well density was not assessed and only taken on the regressors in order to preserve the number of observations. If an output of the regression indicated statistical significant in any of the logs of the demographic variables, that meant that a 1% change in either population density, median income, or percentage of non-white variable meant a $\beta/100$ change in well density. The log transformed variable coefficients in the equation should be read as elasticities.

[26] Because Pennsylvania data only had all groundwater wells available, a regression on the average distances to industrial and commercial wells and sociodemographic indicators would not have given results that necessarily measured the demand for preserving public or social goods

The second set of equations looked at the average nearest distance between unconvention wells and public drinking water per county, where the distance to the nearest public drinking groundwater well for each fracked well was aggregated by county, and averaged. The following models test to see if a statistically significant relationship exists in the distance and social factors of Texan counties:

$$\textbf{EQ 2:}\ P = \beta_0 + \beta_1 N + \beta_2 log(D) + \beta_3 I + \beta_4 T$$

$$\textbf{EQ 2.2:}\ P = \beta_0 + \beta_1 N + \beta_2 log(D) + \beta_3 log(I) + \beta_4 T$$

$$\textbf{EQ 2.3:}\ P = \beta_0 + \beta_1 N + \beta_2 log(D) + \beta_3 log(I) + \beta_4 log(T)$$

Where:

P = Average distance of nearest public drinking well from fracked oil/gas well (feet)
N = Percentage of Population that identifies as a race other than "White" per County
D = Population Density (people per acre)
I = Median Income per County
T = Percent of voters who voted for the Republican Candidate in 2016 Presidential Election per County

For the proximity equations, the equation 2.0 shows that only the log of population density was taken as a linear correlation between income and regulatory imposition is assumed; since income is also generally linearly correlated with race, the percentage of the non-white population was also kept linear. Only the log of population density was taken. In equations 2.1 and 2.2, both median income and 2016 voting patterns were also log transformed to test if these transformations would help increase model fit in terms of R-squared and adjusted R-squared.

The last model conducted as part of this research tested the relationship between unconventional wells and public health. Data from a Robert Wood Johnson Foundation program, County Health Rankings[27], was used to extract regressors for Texas county health indicators. The metric for poor health, "defined as the percentage of adults within a county reporting poor or fair health" was used as the dependent variable while "percent severe housing" and "percentage of children in poverty" were used as regressors, in addition to the previous socioeconomic indicators.

EQ 3:

$$log(H) = \beta_0 + \beta_1 Wd + \beta_2 W + \beta_3 P + \beta_4 log(N) + \beta_5 log(I) + \beta_6 log(C) + \beta_7 log(L)$$

EQ 3.2: $log(H) = \beta_0 + \beta_1 W + \beta_2 log(I) + \beta_3 log(C) + \beta_4 log(L)$

EQ 3.3: $log(H) = \beta_0 + \beta_1 log(I) + \beta_2 log(C) + \beta_3 log(L)$

Where:

H = The percentage of adults that report poor or fair health per County

Wd = (Well density) Hydraulically fractured wells per acre per County

W = Total number of fracked wells per County

P = Average distance of nearest public drinking well from fracked oil/gas well (feet)

N = Percentage of Population that identifies as a race other than "White" per County

I = Median Income per County

C = Percentage of Children in Poverty per County

L = Number of households with severe housing problems[28] per County

The set of equations for public health models employed a reductive look at how the well count affects the model fit by gradually removing unconventional well variables to see the effect of socioeconomic and health indicators alone. Variance inflation factors were calculated for each instance to check multicollinearity between variables, and all regressors had VIF values of less than 10 for each iteration of the model. While more health indicators were available for use in the model, such as

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[27] "Texas Downloads." n.d. County Health Rankings & Roadmaps. Accessed April 14, 2020. https://www.countyhealthrankings.org/app/texas/2018/downloads.

[28] Defined as having at least 1 of 4 problems: overcrowding, high housing costs, lack of kitchen, or lack of plumbing

percent rural population, the variables selected were based on qualitative assessment of indicators that might most impact public health without inflating the R-squared statistic through many regressors.

Additionally, simple linear regressions were done on well count with county level employment for Pennsylvania in the sectors said to benefit most from increased fracking through the I/O models (Hassett and Mathur 2013)(Wobbekind and Lewandowski 2014), which includes Business and Management, Transportation, Service, Construction and maintenance, and Oil and Gas Extraction sectors using employment data from the 2017 economic census.

Shift Share Analysis

Drawing on methods of standard regional economic analysis, a shift-share analysis[29] (Dunn et al, 1960) was performed instead to provide a descriptive framework for assessing the industry potential of American states and shifts in labor industries before major fracking legislations were imposed, and afterwards. Using the year when the earliest regulatory change of the four states occurred, year 2012 is used as a benchmark for the original year of the analysis, while 2018 is to represent most present data. Though shift-share analysis has more traditionally been performed at a county level (Chen and Xu 2005), this study defines the entirety of the four states, New York, Pennsylvania, Texas, and Illinois, as the regions for regional share analysis (RS). The expansion of regional analysis to states is possible as states are merely aggregations of individual counties and no limiters are placed on the maximum size of a region for analysis, granted that the study areas are smaller than national share (NS) boundaries, which comprises the entire United States. The applicability of shift-share analysis outside of purely

[29] Edgar S. Dunn, 1960. "A Statistical And Analytical Technique For Regional Analysis," Papers in Regional Science, Wiley Blackwell, vol. 6(1), pages 97-112, January.
Rosenbluth, Gideon. "Input-Output Analysis: A Critique." *Statistische Hefte* 9, no. 4 (December 1, 1968): 255–68. https://doi.org/10.1007/BF02927705.

economic research is well documented and has been used previously by Jayanthakumaran & Liu[30] in a 2011 study of shifting pollutant emission trends across Australian states, which presents a departure from standard shift-share usage in both scale and scope. Shift-share analysis has even been applied in sociological studies on changes in gender distribution[31] (Lyson 1981). This study uses shift-share analysis to analyze the changes in employment by industry, examining the National Share, Industrial mix effect, as well as the regional shares of each industry surveyed by the ACS. Particular attention is given to changes in the expanded Construction, Extraction, and Mining sector under NAICS code 211, which specifically refers to oil and gas related production and extraction activities.

This study starts the shift share analysis by looking at the changes in industry employment from 2012 and 2018 by comparing the local industry growth at a state level with national growth. In doing so, we will look at the Industrial Mix effect (IM), National Share effect (NS), and Regional Shift effect (RS) for New York, Pennsylvania, Texas, and Illinois. The total shift share analysis formula can be written as:

$$SS = NS + IM + RS$$

National Share

NS explains how much of the local industry growth is explained by the overall growth of the national economy-- in essence, if there is an overall national growth in the industry, one might expect there to be growth locally across the board. We can calculate it as:

$$RE2012 * (NE2018/NE2012)$$

[30] Jayanthakumaran, Kankesu, and Ying Liu. "Trends in Emissions across the States of Australia 1998-99 to 2007-08: A Shift-Share Analysis." *Agenda: A Journal of Policy Analysis and Reform* 18, no. 1 (2011): 53–66.
[31] Lyson, Thomas A. "The Changing Sex Composition of College Curricula: A Shift-Share Approach." *American Educational Research Journal* 18, no. 4 (1981): 503–11. https://doi.org/10.2307/1162636.

where

RE2012: Number of local jobs in an industry in 2010

NE2018: Total US jobs 2018

N2012: Total US jobs 2012

Industrial Mix Effect

IM effect represents the share of the regional industry growth that is explained by the growth of the specific industry at a national level. IM is calculated by subtracting the national share of the total economy from the national share of a specific industry applied to the local jobs in that industry. We calculate it as:

$$(RE2012 * (Ni2018/Ni2012)) - NS$$

where

Ni2012: Total US jobs in specific industry 2012

Ni2018: Total US jobs in specific industry 2018

Regional Shift

Regional Shift is the difference between the national share and the industry mix and indicates whether or not local conditions were responsible for the growth in local industry. We calculate it as:

$$RE2010 * (RE2018/RE2012 - Ni2019/Ni2012)$$

The sum total of all three allows for a broader overview of the changes happening in employment by industry, and which industry growth is more attributable to the states that is not due to overall market growth in the US or industry sector-level growth.

Data Sources

Sociodemographic Data

This study relied primarily on 2012 and 2017 American Community Survey 1-year estimates for the bulk of the initial shift share analysis for Illinois, New York, Pennsylvania, and Texas at the state level, as the data from the US economic census were coincidentally available in both years. Historical analysis of employment changes over time pulled from ACS 1-year estimates from 2010 to 2018 also at the state level. Median income data and demographic data for logistic regression models were gathered at the county level using the 2012 and 2017 ACS 5-year estimates, with income adjusted to 2019 dollars based on the Consumer Price Index (CPI) set by the Bureau of Labor Statistics.

Hydraulically Fractured Well Data

Most up to date publicly available well data on hydraulically fractured wells across the USA was obtained through the FracFocus website. The raw files were extracted and cleaned, all 20 versions of the database merged with duplicates removed. The data provided the latitude and longitude coordinates of registered well permits, date of issue, well operation start date, end date, amount of water used per well, and the chemical fluids used for fracturing. After sorting and cleaning, the well data is then grouped into two sets, one containing wells constructed before 2012, and another set with wells constructed after 2012. Because the method of data entry was not uniform, multiple labels for the same states[32] rendered state and county columns unreliable for joins and grouping of data. Instead, GIS software was used to convert longitude-latitude as point data.Three distinct geographic coordinate systems recorded for every well entry: NAD83, NAD27, and WGS84, and all were projected onto the US Contiguous Equidistant Conic coordinate system to preserve distance calculations between points. All points were then spatially joined for county level analysis.

Groundwater Sources

GIS shapefiles and location data were gathered from the state agencies overseeing water resources of Texas and Pennslyvannia respectively. The Texas Water Development Board (WDB) provided reports and downloadable databases of groundwater well locations, containing updated information regarding the major aquifers the well extracts from, well depth, availability of water quality, and primary use of the well[33]. Because the was then filtered for by use, and only public drinking wells were selected for the purposes of this study. Similarly, groundwater well data for Pennsylvania was provided for through the Pennsylvania Department of Environmental Protection (DEP) Open Data portal[34], and all wells that were not classified as for use by "oil and gas" and site status listed as "active" were used for the analysis[35]. Because the information regarding groundwater wells varied in information provided depending on state, the analysis of each state should not be understood as a collective, and seen more as a comparative analysis. For Texas, the availability of "public drinking wells" as a classification allows for a more pinpoint focus on the proximity of

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[32] I.e. "PA" or "Penn" were used interchangeably with "Pennsylvania", and certain state names were sometimes misspelled
[33] "Groundwater Data | Texas Water Development Board." Accessed March 16, 2020. http://www.twdb.texas.gov/groundwater/data/gwdbrpt.asp. Updated 2019
[34] "PA Department of Environmental Protection." Accessed March 16, 2020. https://newdata-padep-1.opendata.arcgis.com/.
[35] This selection included 8005 of 8453 total PA groundwater wells; "public drinking wells" was not a use listed in the dataset

unconventional oil and gas wells near water sources that are directly purposed for consumption, while in Pennsylvania, no such direct public health risks can be drawn and only a spillover effect can be loosely assumed in terms of possible well to well water contamination. An analysis of well locations and major aquifers was considered, but an initial examination of wells and aquifer areas showed that most aquifers overlapped with major shale basins, and would have provided no distinct insight into existing spatial distributions beyond the unhappy coincidence of natural geological formations.

Energy Market Data

Overall contextual understanding of the economic and social costs and benefits of hydraulic fracking regulations are analyzed using information provided by the US Energy Information Administration (EIA). The EIA manages macroeconomic market data on import and exports of tight oil to and from the United States, including historical data on production, extraction, fuels and electricity prices over time. This data is not used as part of the models made for this study, but allows for a broader overview of fracking's role both domestically and globally.

Research Limitations and Constraints

Shortcomings in research largely far in the availability and uniformity of the data being used. In an ideal research situation, data would be collected through a single entity and standardized in column names, data type, and circumstances of the collection. However, as each state and county utilizes its own independent method of data collection, the quality and accuracy of the well data cannot be cross referenced or verified. Furthermore, while FracFocus is used by states and by federal agencies as a reliable source of information on registered unconventional wells, it does not necessarily contain every fracking oil and gas well in the nation. Pennsylvania and Texas both do retain independent records of known oil and gas wells by county, but the information is neither uniform across the states nor necessarily available as a public database.

Sociodemographic information all come with a margin of error, which is tend to be greater in 1-year estimates than in 5-year estimates, according to the US Census Bureau[36]. The tradeoffs between the 1-year estimates and 5-year estimates lie in their currency and reliability, with 1-year estimates being the most current data available, but less reliable than data collected over a 5-year period for the year. Hence, while ideally the same datasets would be used across all facets of the analysis, certain estimates provide a better use-case for the type of analysis. In addition, certain data such as IPUMS and the Economic Census are only available in certain years. Furthermore this research would have benefitted from an aggregated data file of residential zones by state, but is unlikely especially given that Texas does not employ traditional zoning.

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[36] Bureau, US Census. "When to Use 1-Year, 3-Year, or 5-Year Estimates." The United States Census Bureau. Accessed March 16, 2020. https://www.census.gov/programs-surveys/acs/guidance/estimates.html.

Given time constraints inherent in this thesis, the scope of the research was greatly limited and many variables examined reduced due to the difficulty in locating the data, acquiring a large enough sample size to validate, and the inability to physically survey sites due to the Covid-19 pandemic. The hope is that this research can lay the foundations for further examination of the sociological as well as regional economic impacts of unconventional oil and gas well regulation.

The methodology would have also greatly benefitted from an exact replication of strategies used in prior studies, such as the use of I/O models like IMPLAN as a check against the data being used to reach the conclusions in previous reports. The inaccessibility of proprietary economic models or the multipliers used makes a direct comparison of cost/benefit analysis difficult; though multiple attempts were made to contact authors and agencies of published reports, no response had been received. Therefore, the conclusions reached as a part of this study are neither direct refutations of previous studies, nor a supplement to them. Rather, this thesis should be understood as a separate and distinct attempt to test the underlying assumptions that were taken for granted in previous studies, which produced strong broad recommendations based only on the fiscal and market outputs of their I/O models without significant attention to the socioeconomic considerations at a smaller, local scale.

If this research was to be extended to next steps, I would like to be able to conduct a more comprehensive policy review of all counties on top of US sedimentary basins, and build out a database of the existing zoning setbacks for each county. This would have allowed more robust analysis of the spatial influence of local fracking regulation outside of only Texas and Pennslyvannia, as well as test whether or not the clustering seen in the results from Texas counties may apply nationally. The data can then be used as factors to model the relationship between setback distance, unconventional well density, and public health. Further studies should also look into water usage patterns of regions that are drought prone but have high oil well densities, to see what systems are in place to offset the heavy usage of local water sources. Furthermore, a wider range of social costs should be examined with respect to the presence of fracking, such as infrastructure spending, air quality, child mortality rates, mental health outcomes, and noise levels.

V. FINDINGS

The presentations of findings are divided by the order of research questions, approached through both a quantitative explanation of results, and a more qualitative analysis of how the results can be perceived in the context of regional planning.

Part I

What is the existing geospatial distribution of unconventional oil and gas wells with respect to groundwater sources?

Existing Zoning and Regulation

While the majority of unconventional drilling can occur anywhere along the major US shale basins, the distinct and disparate nature of US state and local regulations from state to state and county to county determine both the density of unconventional oil wells and its proximity to active groundwater sources.

Looking first at Texas, where state legislation takes priority over local laws and federally regulated offshore fracking operations are infrequent compared to private drilling, the regulatory measures surrounding hydraulic fracturing actually fall within a middle ground between comprehensive regulation, and minimal regulation. Texas leads the US in tight oil production in barrels per day (BPD) as top five states producing the most crude oil[37]. According to EIA, Texas alone accounts for 40.5% of US gross crude oil production, vastly outpacing North Dakota which is the second leading producer at 11.5%. This is largely attributable to Texas's location on top of both the Permian and Eagle Ford shale basins; as of the most recent March 2020 Year-Over-Year Summary on drilling productivity report by the EIS, the Permian basin leads in projected tight oil and shale gas

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[37] "Where Our Oil Comes from - U.S. Energy Information Administration (EIA)." Accessed March 17, 2020. https://www.eia.gov/energyexplained/oil-and-petroleum-products/where-our-oil-comes-from.php.

production for April 2020 at approximately 4,800,000 BPD, while the Appalachian basin leads in natural gas production at 3,300 million cubic feet per day. General regulatory power to regulate and oversee oil and gas drilling activity in Texas is given to the Railroad Commission of Texas (RRC), which was established in 1891[38]. Though most counties in Texas are friendly towards oil and gas activity, certain towns and cities have pushed back on the amount of drilling through local ordinances. The first instance of setback distances imposed on oil and gas activity in the city of Fort Worth in 2001, when the municipality adopted a 300ft setback to drilling, later expanding that to 600ft following increased nuisance complaints[39]. An air quality study commissioned by the city and published on the Fort Worth government site concluded that a 600ft setback was sufficient to mitigate any negative impacts of drilling to residents[40]. Other towns and cities followed suit, In 2013, Dallas established a 1500 ft setback between gas wells and residences[41], which critics and oil and gas industry members claim is effectively a ban on fracking. The City of Denton took the most drastic action and imposed a complete ban on fracking in 2015. On May 19, 2015, Gov. Greg Abbot signed in law a bill that prohibits cities and towns in Texas to ban hydraulic fracturing[42], severely curtailing the ability of local municipalities to impose restrictions. Despite this, the local zoning regulations and setbacks continue to be used as a tool for municipalities to exercise a level of control over the placement of unconventional wells. Using survey data gathered by the Texas Municipal League in 2015[43], total of

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[38] "Texas RRC - About RRC." Accessed March 22, 2020. https://www.rrc.state.tx.us/about-us/.

[39] Fry, Matthew, Christian Brannstrom, and Trey Murphy. "How Dallas Became Frack Free: Hydrocarbon Governance under Neoliberalism." *Environment and Planning A* 47 (December 1, 2015): 2591–2608. https://doi.org/10.1177/0308518X15616633.

[40] "Air Quality Study | City of Fort Worth, Texas." Accessed March 22, 2020. http://fortworthtexas.gov/gaswells/air-quality-study/.

[41] ibid

[42] "Texas: Bill Stops Cities From Banning Fracking - The New York Times." Accessed March 17, 2020. https://www.nytimes.com/2015/05/05/us/politics/texas-bill-stops-cities-from-banning-fracking.html.

[43] Murphy, Jim Malewitz and Ryan. "See How Local Drilling Rules Vary Across Texas." The Texas Tribune, March 27, 2015. https://www.texastribune.org/2015/03/27/see-how-local-drilling-rules-vary-across-texas/. Data was extracted from a linked raw csv

337 cities in Texas had municipal officials respond “Yes” to whether or not local restrictions regarding zoning existed in the local county planning codes, 1660 responded “No”, and 1266 cities did not respond or the officials did not know.

No comparable assessment or survey of regulatory or local zoning provisions for Pennsylvania exists in the same capacity as the one by Texas Municipal League. Drilling oversight in Pennsylvania is largely the domain of the Pennsylvania Department of Environmental Protection(DEP), which is in charge of permitting and regulating oil and gas activity[44]. Violations of regulations are reported back to the DEP, which divides the states into six regions, tracking the oil and gas industry compliance with state laws and compiling updates as publicly accessible reports. While the Supreme Court of Texas ruled that the power to regulate fracking fell solely to the hands of the State Legislature in 2015, the Pennsylvania Supreme Court had ruled 4-2 in 2014[45] to overturn a previous ruling that affirmed the Pennsylvania General Assembly’s decision to strip local power to ban or restrict hydraulic fracturing. Specifically, through Chapter 33 of the Oil and Gas Act of 1984 (Title 58 of Pennsylvania Consolidated Statutes), the DEP was granted full authority to establish setbacks and grant variances to oil and gas drilling permits without the input of local municipalities. While the setbacks to water and wells were kept, the ruling invalidated the prohibition of municipalities from enacting local ordinances, calling such imposition unconstitutional, and the guidelines through which the DEP may grant waivers to its “100ft setback from any solid blue lined stream, spring or body of water” and “300 feet between unconventional wells and wetlands” as “unconstitutionally vague”, furthermore

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[44] “Department-of-Environmental-Protection | StateImpact Pennsylvania.” Accessed March 22, 2020. https://stateimpact.npr.org/pennsylvania/tag/department-of-environmental-protection/.
[45] “ROBINSON TOWNSHIP v. COMMONWEALTH | FindLaw.” Accessed March 22, 2020. https://caselaw.findlaw.com/pa-commonwealth-court/1673166.html.

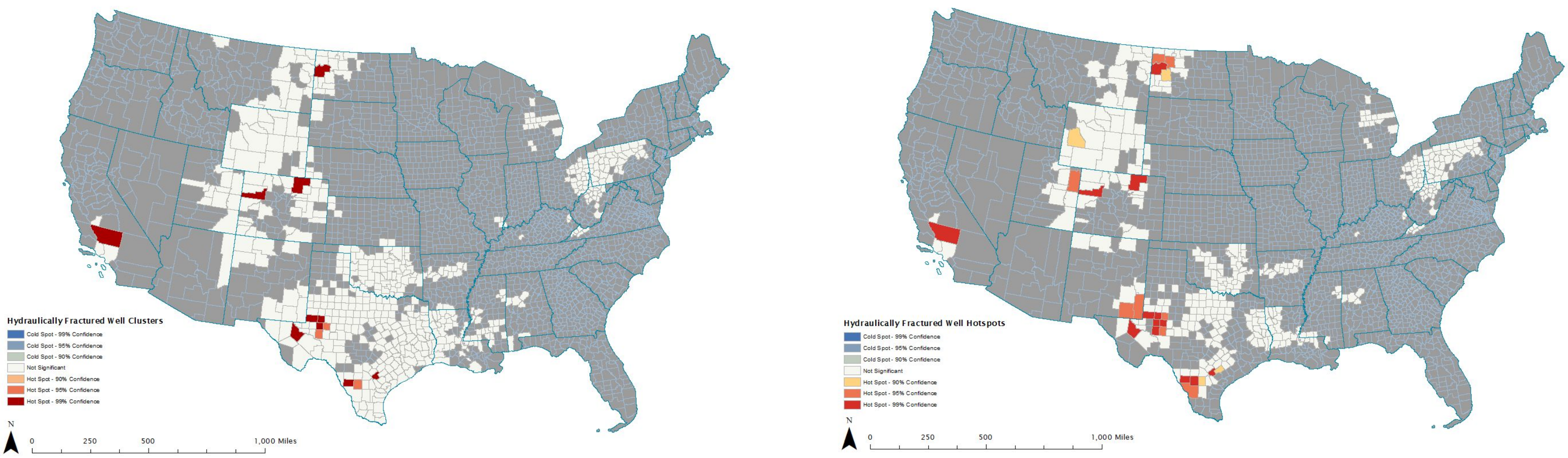
criticizing the DEP for not providing methods for municipalities to appeal the waiver grants and permits for unconventional well activity.

Here, a distinct schism exists between state and county lines, in part distinguishable by the State's attitude towards a municipality's ability to govern itself; Texas, which generally falls under Dillon's Rule with limited home rule homes granted once a city exceeds 5,000 in population and adopts a city charter that is not in conflict with general state laws[46]. Pennsylvania follows both Dillon's rule in legal or regulatory matters not specifically stated in the State's constitution as within the home rule domain of municipalities. Home rule states are therefore allowed a wider latitude to decide on issues such as fracking, which has largely been quasi-regulated through municipal planning ordinances and setbacks, though zoning has historically been seen as a right of the municipality regardless of which principle of governance a state abides by. As increased scrutiny and controversy pushes fracking regulation to the forefront of some state's political agendas, state legislatures have all uniformly tried to consolidate the fracking regulatory oversight as an exception to normal municipal affairs.

[46] "THE TEXAS CONSTITUTION ARTICLE 11. MUNICIPAL CORPORATIONS." Accessed March 22, 2020. https://statutes.capitol.texas.gov/Docs/CN/htm/CN.11.htm#11.4.

Existing Geospatial Distribution

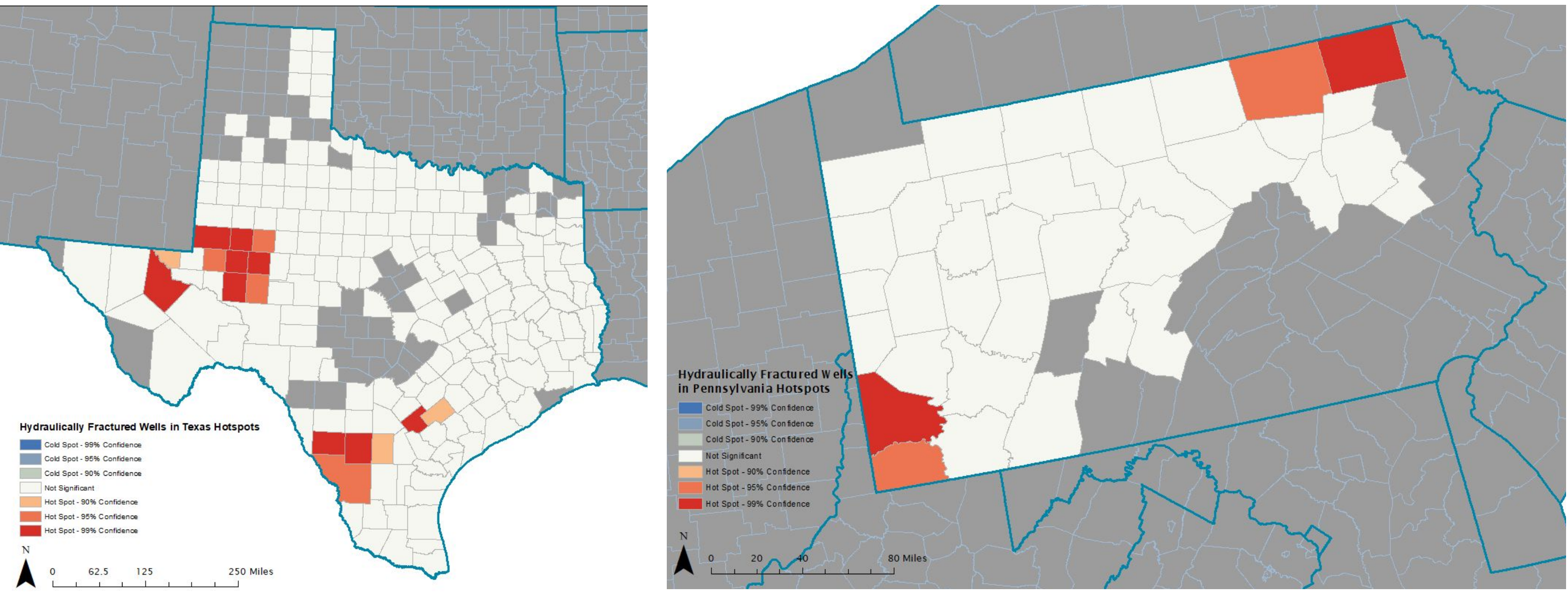
FIGURE 3
Getis-Ord Gi* Hot Spot Analysis Country Level



Counties on top of sedimentary basins (left); Counties on top of existing shale plays (right)

A Getis-Ord Gi* hotspot analysis of existing unconventional wells contained within the Fracfocus database used inverse distance method of calculating well clusters that fell into tiered confidence levels. Three levels of analysis were done: first, using the well count per counties as weights for only counties that lie on top of sedimentary basins (as a proxy for counties with "fracking potential"), second on counties that lie on top of existing major US shale plays, and third on only counties with fracking potential within Texas or Pennsylvania. Because existing the layer information for existing shale plays is too time dependent and potentially self selecting by the oil and gas industry's internal biases, this study did not consider it a good proxy for assessing the fracking potential of US counties; however, as a point of comparison, looking at hotspots for existing shale plays may be a better tool for a high level identification of counties with fracking-friendly local regulations.

FIGURE 4
Getis-Ord Gi* Hotspot Analysis State Level



Texas (left); Pennsylvania (right)

From Figure 4, it is observed that most counties on top of sedimentary basins are not statistically significant in terms of fracked well clustering, and the majority of hotspot counties fall within Texas. More clustering is present when analyzed at the existing shale play level, though it is to be expected because areas of existing shale plays reflect the oil and gas industry's tendency to drill more in areas where resources are more abundant, more easily extracted, or where local regulations were lax . No cold spots were identified at any level of analysis, which may have been an indicator for strict fracking regulations.

Table 2							
Texas Counties Unconventional Well Hotspots							
County	Well Count	2017 Population	Well Density (wells per acre)	Well : People Ratio	Gi* Z-Score	Gi* P-Value	City Fracking Regulation*
Dimmit County	3397	10822	0.00394	0.31	3.53	0.000416	No
Upton County	3159	3575	0.00396	0.88	3.25	0.001153	No
Karnes County	3884	15051	0.00798	0.26	4.1	0.000041	N/A
Martin County	3903	5547	0.00665	0.70	4.12	0.000037	No
Andrews County	4069	17577	0.00423	0.23	4.32	0.000016	No
Midland County	4286	159883	0.0074	0.03	4.57	0.000005	N/A
Glasscock County	3067	1420	0.0053	2.16	3.14	0.001678	N/A
Reeves County	3425	14791	0.00202	0.23	3.56	0.000367	No
La Salle County	3226	7418	0.00334	0.43	3.33	0.000873	No
**Determined by if at least one city within county has local regulation for oil and gas industry*							

In Texas, 9 counties with significant clustering at the 99% confidence level shown in Table 2 were matched with survey responses from the Texas Municipal League, with "No" indicating at least one city within the county responding negative to whether or not local legislation was in place relating to unconventional well drilling. No county had any city with known fracking regulation, with Glasscock county having the highest ratio of unconventional wells to residents and Midland the least, though Midland has the highest net count of unconventional oil and gas wells.

Pennsylvania had only two counties with statistically significant hotspot counties at the 99% significance level so Table 3 includes the other two counties statistically significant at the 95% confidence interval as well (Greene County and Bradford County). Because fracking in Pennsylvania is largely regulated by the DEP with uniform setbacks, individual local laws were not applicable.

Table 3							
Pennsylvania Counties Unconventional Well Hotspots							
County	Well Count	2017 Population	Well Density (wells per acre)	Well : People Ratio	Gi* Z-Score	Gi* P-Value	City Fracking Regulation*
Greene County	1062	37338	0.00289	0.03	2.11	0.035059	N/A
Bradford County	1022	61546	0.00138	0.02	2	0.044985	N/A
Susquehanna County	1408	41716	0.00266	0.03	2.99	0.002728	N/A
Washington County	1356	207661	0.00247	0.01	2.86	0.004193	N/A

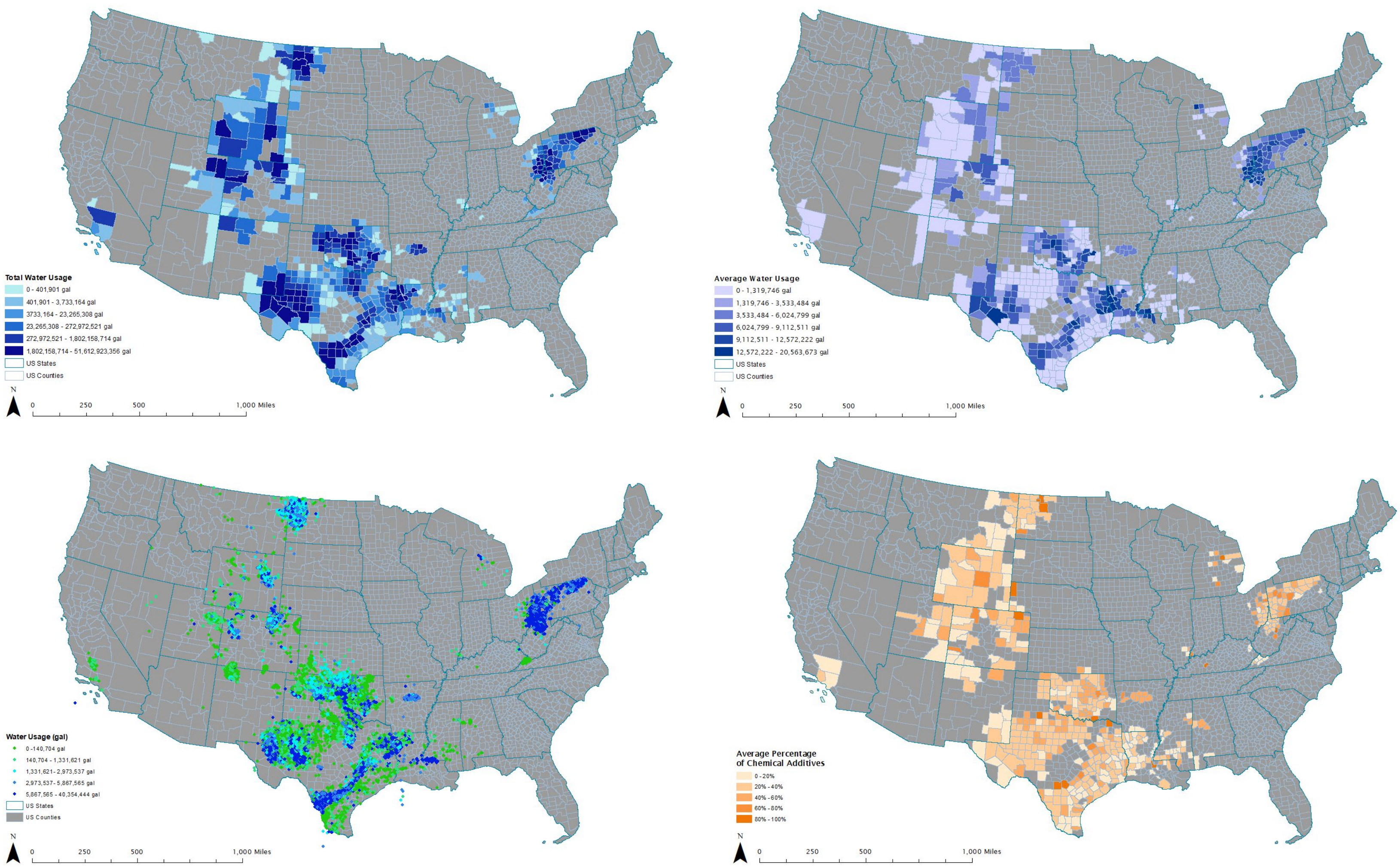
**Determined by if at least one city within county has local regulation for oil and gas industry*

We see from Table 3 that the well to people ratio is significantly lower as the counties in Pennsylvania are more populous than in the Texas counties and have fewer net unconventional wells. Comparing the Gi* Z-score, the noticeable difference in the maximum values highlight why no counties in Pennsylvania showed as statistically significant for unconventional well clusters in the hotspot analysis for all US counties with fracking potential when compared to the Gi* Z-Scores of Texas.

It is important to note that the lack of statistical significance in certain counties does not indicate that the county does not have a high count of unconventional oil and gas wells-- rather, one possible interpretation is that the county may be abundant in wells but surrounded by counties that are less abundant and proportionately fewer. The clustering of hotspots may or may not belie some influence beyond simple industrial logistical efficiencies. While it is almost certain that all clusters indicate a degree of resource abundance and profitable extraction, some may indicate, to a lesser degree, a measure of influence one county's regulatory attitude towards fracking, in the form of public sentiment, may influence another.

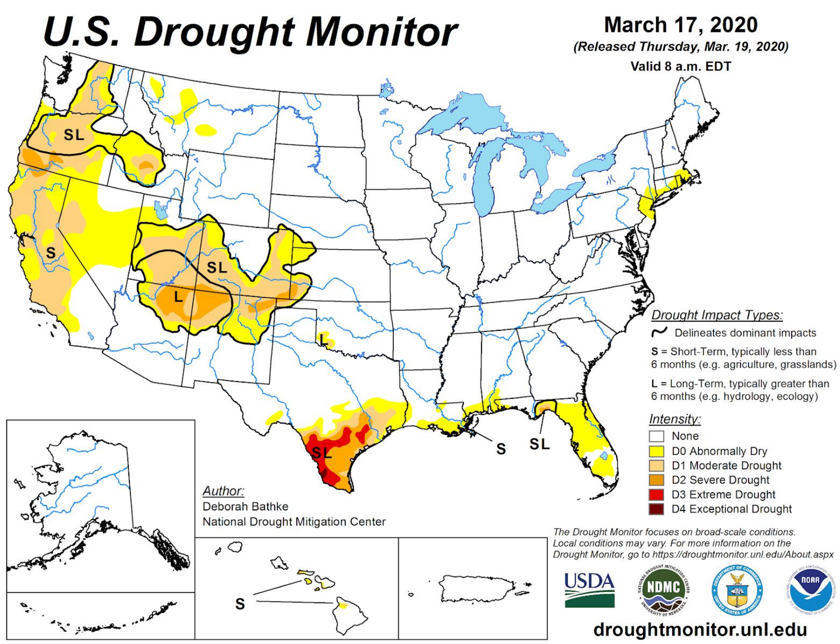
FIGURE 5

Water Usage of Unconventional Wells



Several data columns from the Fracfocus oil and gas well database were aggregated by county to attain the sum total of water in gallons used for oil and gas drilling, as well as the percent of high chemical additives used on average per well per county. Looking at the averaged alone somewhat dilutes the extent of water usage per county, as certain counties are mixed in wells with heavy water usage and little water usage. We can see that the counties identified as significant hotspot zones within US counties on top of sedimentary basins also constitute some of the counties with the highest average and composite water usage for fractured wells. Outside of the previously identified hotspot zones, counties in Pennsylvania and West Virginia have a high concentrated amount of wells with high recorded water usage. When juxtaposed to Fig 6 which shows the most current drought monitoring map by the National Drought Mitigation Center[47], the concerns over excessive water usage is made more apparent in states with large areas of moderate to extreme drought like Colorado and Texas. Referring back to Fig 4, we see that the previously identified hotspots of significant unconventional well clusters intersect the locations of extreme drought in the southern part of Texas.

FIGURE 6
U.S. Drought Monitor Map (3/17/2020)



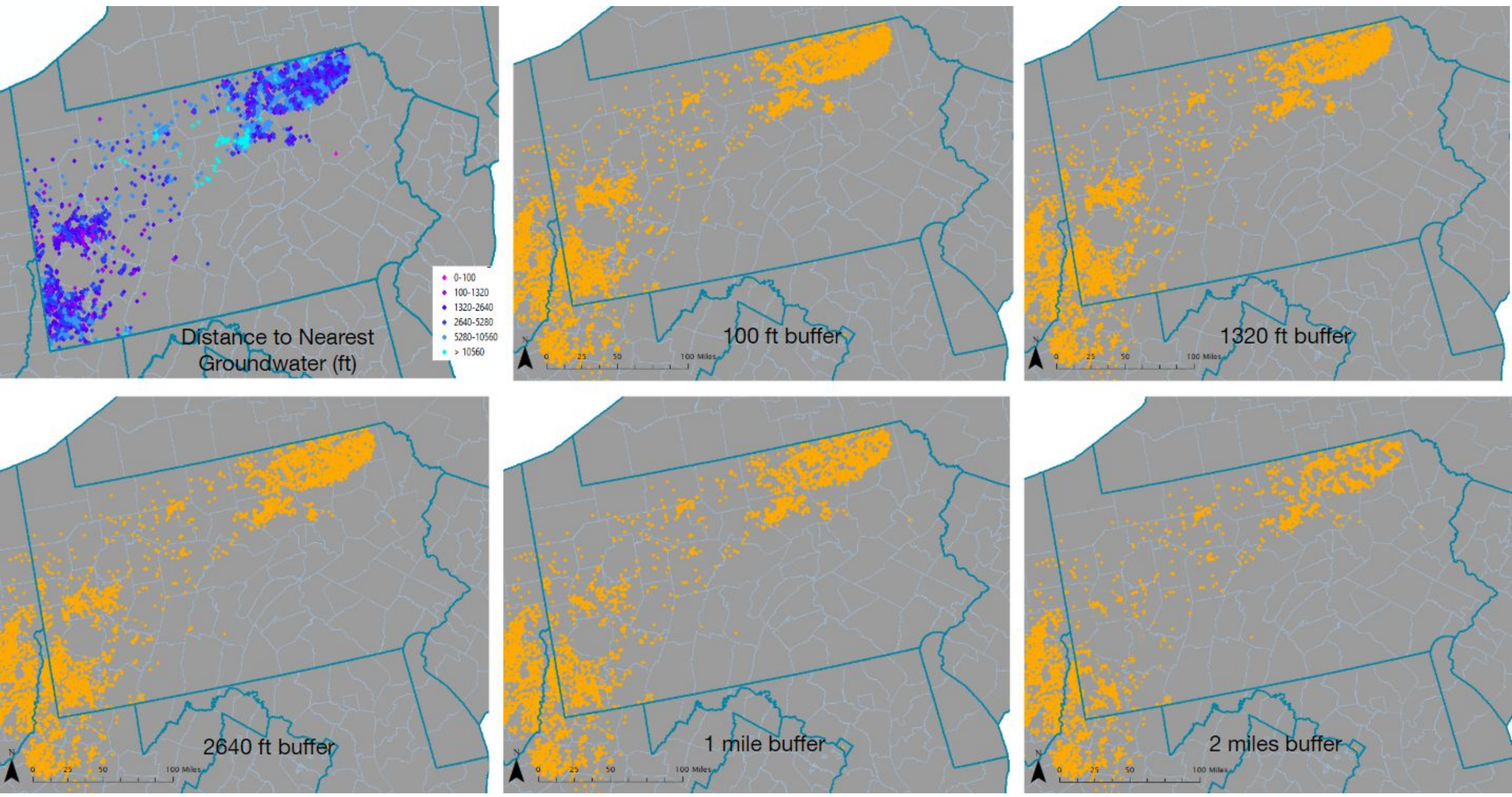
Data: National Drought Mitigation Center

[47] "Current Map | United States Drought Monitor." Accessed March 22, 2020. https://droughtmonitor.unl.edu/.

Applying Zoning Buffers & Setbacks

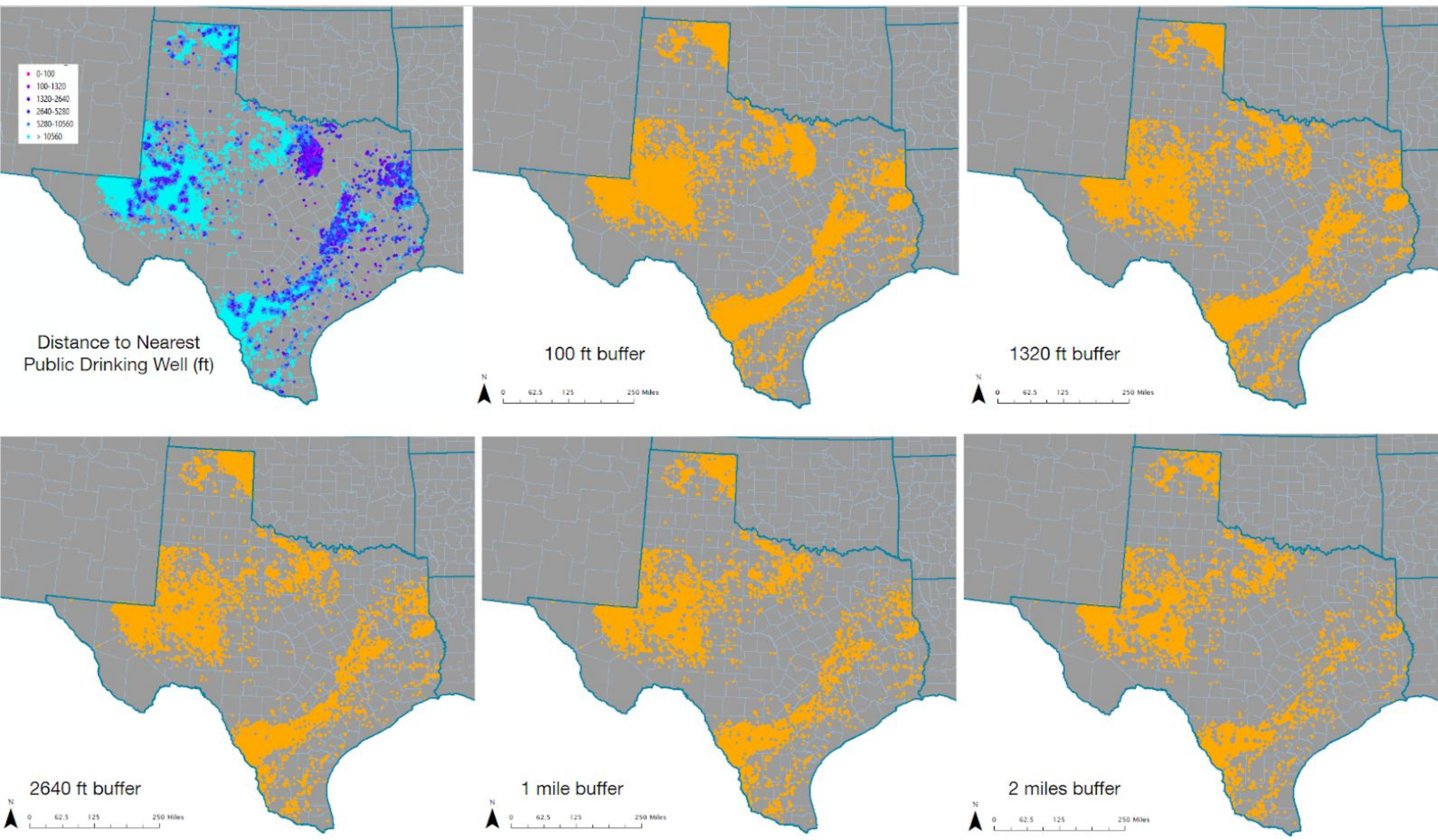
One of the main research questions this study seeks to answer is whether or not a uniform application of setback distances from 100ft to 2 miles from an existing groundwater source or public drinking well would act as a de-facto ban on hydraulic fracturing activities and prevent the oil and gas industry from drilling in major sedimentary basin areas.

FIGURE 7
Unconventional Well Reduction Scenarios in Pennsylvania



Buffers shown on Table 1 were applied to every recorded groundwater well designated for public drinking water in Texas, and all industrial, agricultural, and commercial uses for Pennsylvania (no separate data for public drinking use was found for Pennsylvania). Figure 7 shows the gradual reduction of unconventional wells in Pennsylvania as not being markedly pronounced until the ½ mile buffer, and then significantly more visible at the 1 mile and 2 mile buffers. The concentration of fracked wells closest to existing groundwater wells is highest in Butler, Armstrong, Washington, Bradford, and Susquehanna counties, which coincides with all the statistically significant fracked well hotspots at the 95% confidence interval and above.

FIGURE 8
Unconventional Well Reduction Scenarios in Texas



In Texas (Figure 8), we similarly see a lack of visible disruption to the existing fabric of unconventional well distribution at 100ft, but the change is quicker to appear at the 1320ft buffer (¼ mile). Significant reduction to existing fracked wells can be seen at the 2 mile buffer scenario, with the eastern portions of the state showing the most reductions. Unlike in the Pennsylvania scenario, the groundwater features selected were only those classified as “public drinking wells”, which may have reduced the number of unconventional wells captured in the buffers. We can anticipate that a further expansion of groundwater well types included in the analysis to wells used for agricultural, industrial, and commercial sectors will greatly increase the net buffer areas.

TABLE 4							
Unconventional Wells Captured by Buffer Distances							
State	Type	Total Fracked Wells	100ft	1320ft	2640ft	5280ft	10560ft
Texas	Public Drinking Well	78805	0	397	1210	3702	10157
Pennsylvania	Groundwater Wells	8711	4	43	247	922	3349

Table 4 shows the total counts of unconventional wells captured by each buffer. If a uniform zoning setback of 1 mile was imposed on either state, Texas would lose approximately 4.7% of its existing hydraulically fractured oil and gas wells while Pennsylvania would lose 10.58%; the number jumps exponentially for both states at the 2 mile setback mark, with Texas standing to lose 12.89% of its unconventional wells, and Pennsylvania losing 38.45%. Cross referencing back to the 2017 study by Jasechko and Peronne which used Fracfocus fracked well data from 2000-2014 to conclude that 37% of recorded public and private unconventional wells were within a 2 km distance from a public drinking well in states with more than 100 instances of fracked wells, the new figures using the 2019 well data roughly corresponds to previous findings, though the number of unconventional wells in the US has more than doubled from 2014 to 2019. This increase in hydraulically fractured wells over analysis periods is not assumed to be evenly spread, and we can see that in states with high incidence of clustering, that the geospatial distribution of well activity can greatly affect the percentage captured by the setback buffers. In this case, because Pennsylvania has a smaller net count of unconventional wells, the percentage captured by any setback buffer is proportionally greater than in Texas than in Pennsylvania. This is compounded by the lack of ability to isolate only public drinking wells in Pennsylvania. A significant increase in unconventional wells placed in counties with lower population density can dilute the effect of state level setbacks; even though the total number of wells captured by 1 mile and 2 mile setbacks may have experienced a net increase, a total increase in the state fracked well count would water down the percentage to the 10.58% we see here.

These results indicate that the amount of appropriate setback for each state considering minimum zoning setbacks on unconventional oil and gas wells will vary in its impact and on its total shale play potential. However, in both cases, local or state legislation has already prevented most wells from being within 100ft of a public drinking well or groundwater well, and the impacts are not as severe even at a ¼ mile setback distance.

Part II

Do existing drilling codes create equitable social distribution of unconventional wells?

Logistic Regression Analysis

Demographic Change

To see if a change in the demographic makeup of a county has a relationship with the amount of fracking between 2012 and 2017, a regression was done using variables for percentage change in percentage of nonwhite race population and median income over the 5 years (see Appendix Figures 1 and 2). The resulting model output shows no statistically significant relationship between a change in any of the three variables and a change in fracking, which in general has increased for every county where fracking was available. The model also showed low multiple R-squared values less than 0.1, indicating that the data is noisy in terms of variability, and that the fit is less than ideal. Because an increase in fracking has also a documented “boom” effect on regions, the dependency for median income and well count are tested again in reverse with percent change in median income as the dependent variable and change in number of wells as independent as case 2, again with no statistically significant factors. In this case, we fail to reject the null hypothesis that a change in well count significant increases the median income of a county.

Demand for Fracking in Texas

Since Texas has made the location data for public drinking wells publicly accessible, this study utilized the data to examine the geospatial distribution of well densities from a social equity standpoint-- that is to ask: is there a significant difference in well densities depending on socioeconomic characteristics of a community? Moreover, do lower income and more diverse neighborhoods bear a larger social burden of having more fractured wells? Lower income areas may demand more fracking to boost employment and the local economy, whereas the areas with more high income, white residents might oppose a large quantity of oil and gas rigs in their neighborhood. The following models were made to test the hypothesis that there indeed is a social stratification of demand for fracking at the cost of public health and open space.

EQ 1: $Wd = \beta_0 + \beta_1 \, log(N) + \beta_2 \, log(D) + \beta_3 \, log(I) + \beta_4 T$ [48]

EQ 1.2: $Wd = \beta_0 + \beta_1 \, log(N) + \beta_2 \, log(D) + \beta_3 \, log(I) + \beta_4 \, log(T)$

TABLE 5
Effect on Fracking Density

Demographic Variables	Equation 1	Equation 2
log Median Income	0.001841	1.88E-03
	(5.41E^-7) ***	(3.87E-07) ***
log Population Density	-0.0001312	-1.47E-04
	(0.00385) **	(0.000881) ***
log Percent Non-White	0.0008846	7.90E-04
	(2.33E^-6) ***	(6.11E-06) ***
% Voted Republican 2016	0.00001346	
	(0.03391) *	
log % Voted Republican 2016		5.00E-04
		(0.107372)
Constant	-0.02004	-2.17E-02
	(4.07E^-7) ***	(4.32E-08) ***
R-squared	0.1698	0.1634
Adjusted R-squared	0.1564	0.1499

Significance levels are denoted as follows: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$

[48] Definitions:
Wd = (Well density) Hydraulically fractured wells per acre per County
N = Percentage of Population that identifies as a race other than "White" per County
D = Population Density (people per acre)
I = Median Income per County
T = Percent of voters who voted for the Republican Candidate in 2016 Presidential Election per County

We can see from Table 5 that all regressors for equation 1 returned statistically significant, with a multiple R-squared of 0.1698. The low multiple R-squared score indicates that the sociodemographic indicators may not explain variance in the well density well, and that there may be more factors that influence well density than noted here. However, the significance of median income, population density, and percentage of non white lends credence to the initial hypothesis of socio-economic influences on fracking density in Texas. From the results, we see that 1% increase in median income corresponds to a 0.00002 increase in oil and gas well density per county, and a similar positive increase in fracking density as the county becomes less white. Population density shows an inverse relationship with fracking density, with a marginal decline in well density as population increases. Overall, the coefficients are too small to model a realistic effect as sociodemographic characteristics do not vary significantly year to year. In general, however, we can see that the demand for fracking goes down with more people, but that is offset by the demand for fracking in areas with more income and more diversity.

We repeat the regression using average distance to nearest public drinking water in feet as a proxy for looking at the demand for local fracking regulation. The initial hypothesis is that areas with higher income will object more to potential public health hazards, which include chemical spillovers and air pollution. As a greater regulation favors greater distance between oil and gas wells and public drinking wells, this study anticipates a positive correlation between median income, population density, and proximity to drinking well, and a negative correlation between percent non-white and proximity.

EQ 2: $P = \beta_0 + \beta_1 N + \beta_2 log(D) + \beta_3 I + \beta_4 T$ [49]

EQ 2.2: $P = \beta_0 + \beta_1 N + \beta_2 log(D) + \beta_3 log(I) + \beta_4 T$

EQ 2.3: $P = \beta_0 + \beta_1 N + \beta_2 log(D) + \beta_3 log(I) + \beta_4 log(T)$

TABLE 6

Effect on Proximity to Public Drinking Water

Demographic Variables	Equation 1	Equation 2	Equation 3
Median Income	0.0388		
	(0.348)		
log Median Income		2590	2967.4
		(2.71E-01)	(2.06E-01)
log Population Density	-2950	-2980	-2903.6
	(<2E-16) ***	(< 2E-16) ***	(< 2E-16) ***
Percent Non-White	2010	1970	2130.8
	(0.575)	(0.582467)	(0.513)
% Voted Republican	-168	-172	
	(0.0006) ***	(0.000563) ***	
log % Voted Republican			-9396
			(8.55E-05) ***
Constant	9528	-16349.14	7265
	(0.0521)	(0.520535)	(0.777)
R-squared	0.4077	0.4086	0.4188
Adjusted R-squared	0.3961	0.3971	0.4074

Significance levels are denoted as follows: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$

Table 6 shows that in this case, median income stops being a statistically significant indicator of closeness to public drinking wells in all three iterations, but percentage of nonwhite and especially

[49] Definitions:
P = Average distance of nearest public drinking well from fracked oil/gas well (feet)
N = Percentage of Population that identifies as a race other than "White" per County
D = Population Density (people per acre)
I = Median Income per County
T = Percent of voters who voted for the Republican Candidate in 2016 Presidential Election per County

population density are. The multiple R-squared for equation set 2 shows that the R-squared increases with the log transformation of variables, which indicates that the indicators themselves are not normally distributed. Here in model 2.1, a 1% increase in population density would result in a decrease of 29.5 feet between public drinking wells and unconventional wells, which makes sense since more people in a county also increases the need for public drinking wells, which decreases the amount of elbow room for oil and gas wells. A more interesting observation would be in the percent non-white statistic, where a 1 person increase in the population of non-white ethnicities would result in a 2010ft increase in well distance seems counter to the initial hypothesis. While several interpretations of this phenomenon may be possible, it may be that areas with a high concentration of nonwhite communities in Texas are not well served by public drinking wells, which is likely given the high concentration of fracking in high drought areas.

FIGURE 9
Percent Non-White Population in Texas

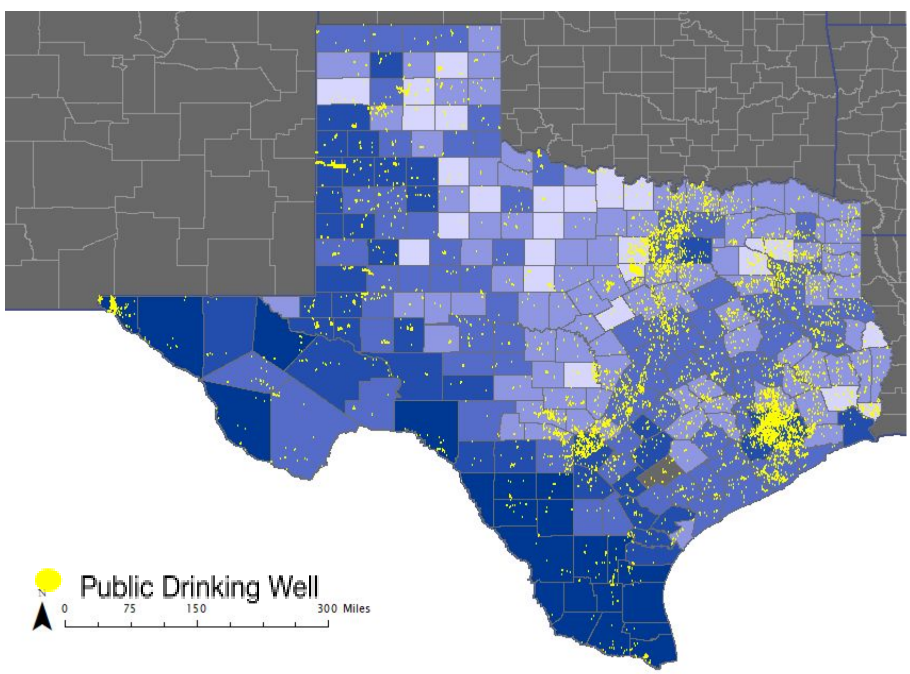


Figure 9 is a chloropleth map showing the perentage of non-white population by county, and the image roughly corroborates with the statistic regression model output about. It's clear from the map that public drinking wells happen to be most heavily concentrated in the eastern portion of Texas, away from the two major sedimentary shale basins on the western region, where a significant proportion of the hispanic and non-white population reside. Rather than being indicative of regulatory decisions made on fracking, the correlation in the near distance model indicates a lack of access to public drinking wells for the nonwhite population, which are concentrated in statistically significant fracking hotspots. Despite the confounding factors, this portion of the study points to more potential for a deeper investigation of other socioeconomic and demographic variables in the geospatial distribution of fracking and water resources.

To better understand if and how fracking affects public health, models were made exploring the relationship between percentage of adults reporting poor health[50] and other social economic indicators in addition to well density and proximity to drinking water.

EQ 3:

$$log(H) = \beta_0 + \beta_1 Wd + \beta_2 W + \beta_3 P + \beta_4 log(N) + \beta_5 log(I) + \beta_6 log(C) + \beta_7 log(L)$$

EQ 3.2: $log(H) = \beta_0 + \beta_1 W + \beta_2 log(I) + \beta_3 log(C) + \beta_4 log(L)$

EQ 3.3: $log(H) = \beta_0 + \beta_1 log(I) + \beta_2 log(C) + \beta_3 log(L)$ [51]

[50] Indicator used states "poor or fair health" being used as a proxy as not reporting "good" health. For the purposes of this study, both are referred to as simply "poor health".
[51] Definitions:
H = The percentage of adults that report poor or fair health per County
Wd = (Well density) Hydraulically fractured wells per acre per County
W = Total number of fracked wells per County
P = Average distance of nearest public drinking well from fracked oil/gas well (feet)
N = Percentage of Population that identifies as a race other than "White" per County
I = Median Income per County

TABLE 7 Effect on Percentage of Adults Reporting Poor/Fair Health			
Demographic Variables	Equation 1	Equation 2	Equation 3
Well Count	1.69E-05	6.531E-05	
	(0.46)	(1.39E-07) ***	
Well Density	-1.318E+00		
	(0.929)		
Nearest Distance to Drinking Well	4.673E-06		
	(2.32E-08) ***		
log Percent Non-White	2.28E-01		
	(<2E-16) ***		
log Median Income	0.01376	-3.10E-01	-0.13970
	(1.73E-05) ***	(0.00107) **	(0.11244)
log Children in Poverty	1.83E-01	2.84E-01	0.36162
	(7.26E-07) ***	(1.19E-06) ***	(2.8E-10) ***
log Severe Housing Problems	8.465E-02	1.750E-01	0.16887
	(2.37E-05)***	(1.03E-08) ***	(2.4E-08) ***
Constant	5.10E+00	4.94E+00	2.88497
	(2.18E-11) ***	(2.64E-05) ***	(0.00806) **
R-squared	0.8524	0.613	0.5527
Adjusted R-squared	0.8473	0.6054	0.5473

Significance levels are denoted as follows: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$

The results of the model again show counterintuitive results; Table 7 shows that equation 3.1, which includes the nearest distance and percent nonwhite variables, indicates an increase in percentage of adults reporting poor health as the distance between unconventional well and public drinking well increases. Several explanations for why it seems that increasing distance would worsen health are

C = Percentage of Children in Poverty per County
L = Number of households with severe housing problems# per County

possible; it could be that in counties without many public drinking wells, water is transported from other counties or regions in Texas which are in close proximity to unconventional wells. Alternatively, the result might have nothing to do with the presence of unconventional wells, but using the proximity variable as a proximity for the effect of drought on health; this explanation is also supported by the low statistical insignificance of both the unconventional well count and well density variables despite the model showing a high fit in terms of R-squared and adjusted R-squared. When both race and proximity variables are removed from the equation, we see in EQ3.2 that the number of wells becomes statistically significant and positively correlated with poor health, albeit with a small coefficient.

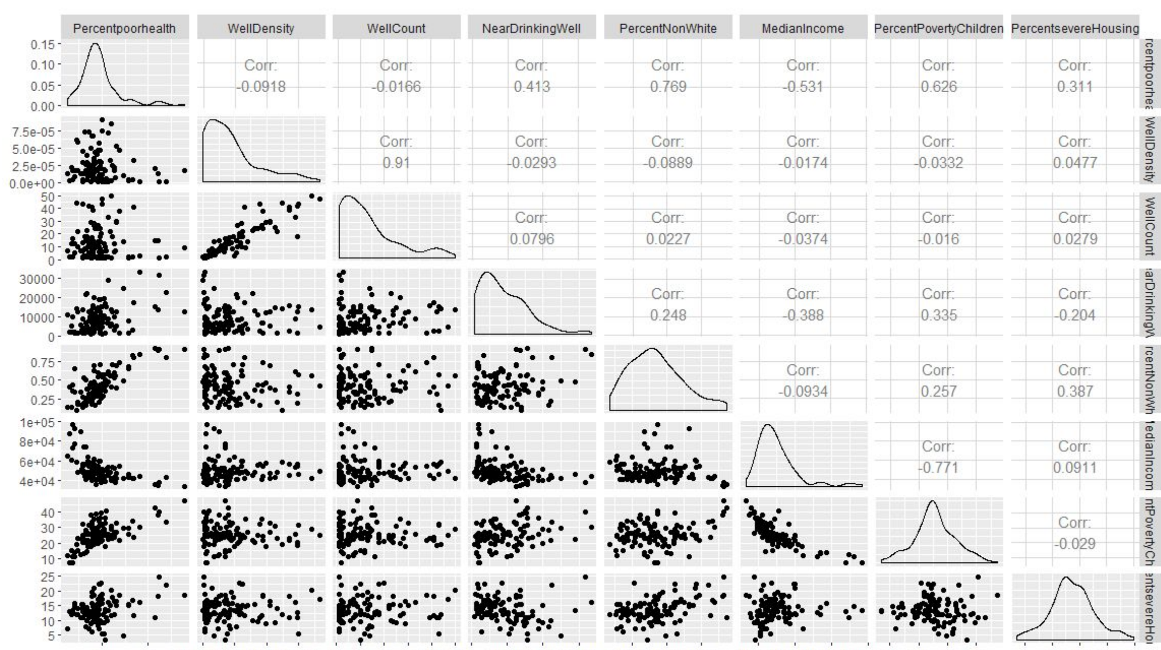
To further gain some clarity on the results, Table 8 shows the descriptive statistics in terms of averages for all variables used in the above equations. Counties were averaged based on well count.

TABLE 8
Texas County Profiles by Unconventional Wells

	All Counties	No Wells	> 0 Wells	1-50 Wells	>1000 Wells
Total Counties	254	43	211	113	21
Average Median Income	$51,386.15	$53,094.63	$51,036.31	$50,023.19	$57,397.90
Average Population Density	0.17 ppl/acre	0.18 ppl/acre	0.17 ppl/acre	0.22 ppl/acre	0.22 ppl/acre
Average % Nonwhite	44.19%	40.09%	45.02%	42.56%	59.67%
% Voted Republican	71.78%	73.10%	71.51%	71.07%	68.81 %
Average Nearest Distance Drinking Well	10604.9 ft	NA	10604.9 ft	9043.7 ft	14995.7 ft
Average % Poor Health	19.78%	19.44%	19.85 %	19.43%	21.64%
Average % Children in Poverty	25.09%	25.22%	25.06%	25.55%	22.63%
Average % Severe Housing	14.02%	14.48%	13.93%	13.61%	14.94%

We can see here that the figures for income, race, and well distance, and severe housing variables show a skew in distribution to the left. There's also a sort of bimodal distribution present when the counties are grouped by number of unconventional wells, with a dip in income but categorically better health in fracking counties with less than fifty wells (but at least 1) than counties with no wells and counties with over 1000 wells. Those same counties with less than fifty wells also on average have lower percentage of non-white residents and higher density, though counties with no fracking at all tend to be more white than counties with a signifcant amount of fracking. Looking at the counties with over one thousand wells, it becomes clear that given the density and large distance value, that fracking in Texas overwhelmingly occurs in counties that are populated by nonwhite communities without access to local public drinking groundwater. Because the average median income is higher in high fracking counties, the average percentage of children in poverty is also lower than the state average, though health and housing remain higher than the state average. While no conclusions should be made regarding fracking impacts on water quality and public health based on these results alone, further research should be done to measure the impact of water accessibility in high fracking areas. Figure 10 shows a simple correlation matrix of the above variables; visualized, we can see some linear relationships between poor health and race, and an inverse linear correlation between income and health, though nothing can be said for causation.

FIGURE 10
Percent Non-White Population in Texas



Part III

Would the regulation of fracking activity severely inhibit local industries and employment?

Economic Analysis

To answer this question, an analysis of the industry level changes in income and employment over time is done using a shift share analysis approach to see the overall economic impact of the oil and gas industries on each state. While the main focus remains on Texas and Pennsylvania as comparative case studies for different regions of America with shale play potential, New York and Illinois are introduced in this section of the analysis as additional data points for comparison. New York was chosen in particular for its simultaneous status as a state on top of major sedimentary basins and one with a bonafide fracking ban in 2014, while Illinois is also a state on top of major sedimentary basins that has opened itself for fracking in 2013.

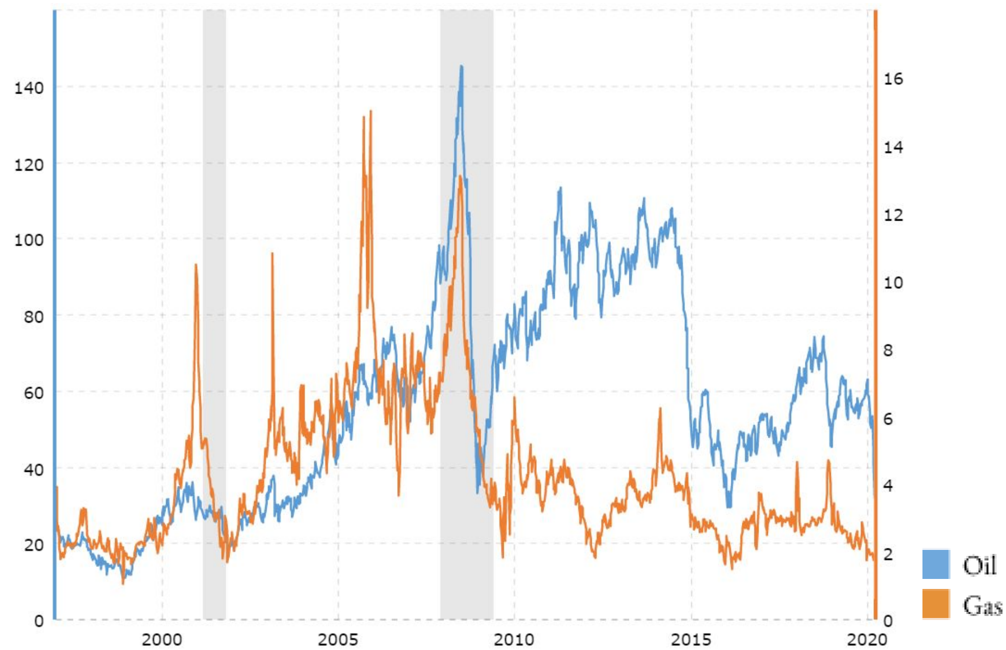
TABLE 9

Employment (NAICS 21)

	2010	2011	2012	2013	2014	2015	2016	2017	2018
IL	11,427	11,228	11,253	10,488	13,213	12,253	9,257	11,966	10,235
NY	6,812	6,404	6,325	5,956	6,867	6,575	7,985	6,530	4,400
PA	26,940	23,691	30,439	34,103	34,218	34,828	26,510	23,482	28,111
TX	209,928	212,826	285,104	309,566	342,215	320,631	254,052	263,002	286,943

Using ACS 1-year estimate data from 2010-2018, the changes in total employment is tracked over the 8 years for four states. Using 2013 and 2014 as potential inflection points for analysis, we see in Table 9 that if plotted, the overall employment curve would look relatively flat, with a momentary bump up from 2013 to 2015, and then rapidly descending again in 2016 for IL, TX, and PA. This movement up and down coincides with the movements in crude oil prices and natural gas prices shown in Figure 11, where despite a convergence of prices starting from the Great Recession 2007-2009, crude oil prices aggressively overtook natural gas in pricing indexes.

FIGURE 11
Crude Oil vs. Natural Gas 10-Year Trend



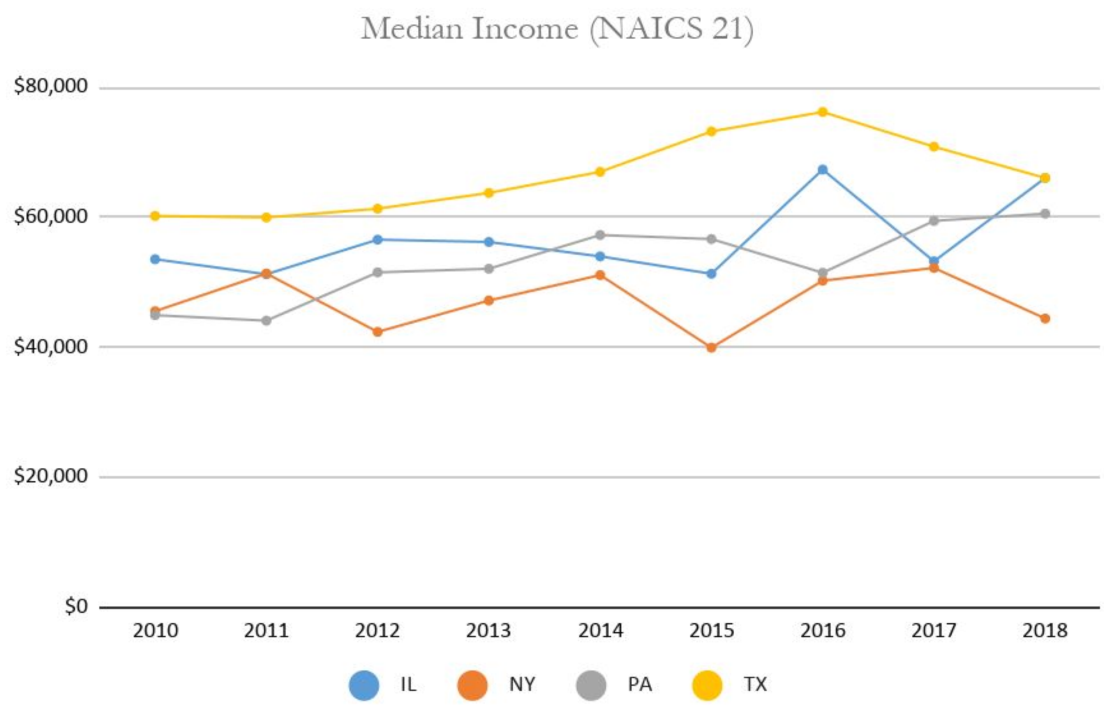
Source: Macrotrends[52]: Henry Hub Natural Gas Index used for Gas and West Texas Intermediate Index used for Crude Oil

Such a correlation to the energy market indicates that the employment is more or less affected by shifts in the overall strength and demand within the oil and gas industry rather than on a natural development or cultivation of the goods, as is the case with technology or other goods and services sectors. New York presents an interesting case where there is no significant change in industry sector employment year to year, and actually increases from 2015 to 2016. This could largely be attributed to its lack of fracking, which provides the largest extraction source of crude oil. The largest gains during

[52] "Crude Oil vs Natural Gas - 10 Year Daily Chart." Accessed March 25, 2020. https://www.macrotrends.net/2500/crude-oil-vs-natural-gas-chart.

peak sector employment was made by Texas, whose exposure to energy market movements is generally more than the other three. Pennsylvania is the only state to see a net gain at the end of 2018 in industry specific employment from 2010 while New York experienced the largest net loss.

FIGURE 12
Median Income for NAICS 21 Industry Sector Workers



Looking further at the median incomes for NAICS 21 sector workers, the data shows a curve similar to the employment curve for Texas, which has the highest median incomes for workers in the oil and gas extraction industry up until 2018, when Illinois sector median income increased to meet Texas's figures. New York shows the lowest median pay for almost all years while the general trend for the other three states shows a slight positive trend. Again, despite a significant increase in the total number of unconventional wells in both Pennsylvania and Texas, neither employment nor sector level median incomes has shown proportion correlation to the well density increases that differs significantly from that of New York, where no fracking happens.

A shift share analysis on all 4 states was done, the results can be seen in Tables 1-4 in the Appendix. Both Texas and Pennsylvania experienced a decrease in total employment within the mining, quarrying, and oil and gas industry with Pennsylvania losing 23% from 2012 to 2018, and Texas experiencing an 8% loss. Pennsylvania underperformed compared to the national net decrease in the sector of 17%; however, these losses may have been compounded by the decline of the coal mining industry, as Pennsylvania is the third highest in US state production of coal. Both New York and Illinois conversely experienced net gains over the 6 years; the shift share analysis of the "industrial mix effect" (IM) shows an across the board decrease in sector level employment due to national industry growth factors, and that the gains made were largely a attributable to the expansion of the national economy (NS) and regional effects (RS). One particular point to highlight is that while the analysis lacks some granularity in separating the decline of the coal industry from possible growth in the oil and gas extraction industry in Pennsylvania, the analysis shows that expansion of oil and gas fracking nevertheless failed to offset the general losses experienced by the NAICS 21 sector as a whole despite the generally strong growth nationally in all sectors across the board; this in part is an argument against the touted benefits in employment made by fracking supporters. Though the shift share analysis for Pennsylvania showed across the board industry employment decline in all sectors except in "transportation, warehousing, and utilities" which may point to an issue with the state economy and labor market, NAICS 21 by far experienced the heaviest loss, with the agriculture sector following in second at -13%.

TABLE 10 2018 Employment Quotient NY/PA								
2018	EMPLOYMENT		SHARE		RATIO OF SHARES	INCREASE IN SHARE		RATIO OF INCREASE
Industry	NY	PA	NY	PA	NY/PA	NY	PA	NY/PA
Agriculture, forestry, fishing and hunting, and mining:	50,480	82,671	0.53%	1.31%	0.40	0.94	0.91	1.029
Agriculture, forestry, fishing and hunting	46,080	54,560	0.48%	0.86%	0.56	0.98	0.93	1.050
Mining, quarrying, and oil and gas extraction	4,400	28,111	0.05%	0.44%	0.10	0.67	0.88	0.759
Construction	545,896	368,589	5.71%	5.82%	0.98	1.02	1.05	0.969
Manufacturing	551,379	733,387	5.77%	11.58%	0.50	0.86	0.96	0.899
Wholesale trade	205,014	162,839	2.15%	2.57%	0.83	0.88	0.94	0.934
Retail trade	941,072	704,752	9.85%	11.13%	0.88	0.89	0.95	0.932
Transportation and warehousing, and utilities:	555,380	352,412	5.81%	5.57%	1.04	1.17	1.12	1.048
Information	266,579	99,820	2.79%	1.58%	1.77	1.00	0.94	1.059
Finance and insurance, and real estate and rental and leasing:	757,363	399,037	7.93%	6.30%	1.26	1.00	1.01	0.986
Professional, scientific, and management, and administrative and waste management services:	1,166,509	663,552	12.21%	10.48%	1.16	1.09	1.09	1.001
Educational services, and health care and social assistance:	2,647,464	1,611,283	27.71%	25.45%	1.09	1.02	0.99	1.033
Arts, entertainment, and recreation, and accommodation and food services:	905,696	516,893	9.48%	8.16%	1.16	1.02	1.00	1.020
Other services, except public administration	467,645	301,820	4.89%	4.77%	1.03	0.98	1.04	0.941
Public administration	444,239	251,890	4.65%	3.98%	1.17	1.00	0.98	1.017
Total	9,555,196	6,331,616	100.00%	100.00%				

Because Pennsylvania and New York are bordering states, the employment quotient and ratio of employment shares was looked at for the two states to see if there can be any corresponding outflow and inflow of employment within the NAICS 21 sector. Previous studies has claimed that stricter regulatory oversight on the oil and gas industry would create impetus for private companies to cease operations within the state and relocate elsewhere; New York and Pennsylvania presents an ideal geographic environment to test those claims as New York also sits on top of the Marcellus Shale region, but has imposed a fracking ban. Accordingly, if the claims of fracking supporters are correct, a net outflow of employment in the New York NAICS 21 sector would be observed with a corresponding increase in Pennsylvania.

Table 10 compares the 2018 industry level employment figures from the 2018 1-year ACS for New York and Pennsylvania. The "Share" values are calculated by dividing the sector employment numbers by the total employed for each state. "Ratio of Shares" is the quotient of NY share values to PA share values, and the corresponding output indicates a labor market advantage in New York's favor if the output is > 1 and in Pennsylvania's favor if the output is < 1. We see that within the NAICS 21 sector, Pennsylvania eclipsed New York in ratio of shares, but may be inflated again due to Pennsylvania's status as a major coal producing state. "Increase in Shares" is the difference in shares between 2018 and 2012 (see Appendix Table 5) while the "Ratio of Increase" is the quotient of increase in share NY and PA. The table shows that despite Pennsylvania's advantage of historical industry specialization in the NAICS 21 sector, the increase in industry shares from 2012 to 2018 is not drastic in its ratio of increase, especially when New York was expected to have a noticeable shrinkage in the oil and gas industry following the fracking ban in 2014. Stepping back and looking at the employment shares at a state level, neither New York nor Pennsylvania can attribute their respective labor market to the NAICS industry, as mining, quarrying, and oil and gas industry only makes up 0.05% of total NY employment, while Pennsylvania has marginally more at 0.44%. The largest share in both states remains solidly in Educational services, Professional services, and Retail trade sectors, with all of agriculture/mining sectors contributing less than 2% to employment shares.

Some regressions were done looking at the impact of unconventional well quantity and industry level employment within Pennsylvania, but none of the models returned statistically significant except when looking at the the percentage of people employed by the oil and gas extraction industry (NAICS 21) with total well count and well density, both of which returned significant at the 0.05 level[53], and in the case of well count, showed an inverse relationship (a net increase in wells correlated to a net decrease in oil and gas extraction sector employment). With an adjusted r-squared of 0.22 and only 28 observations (28 counties with complete data), contrary to what proponents of fracking say, there is not enough data to conclusively say whether or not increased fracking activity will lead to significant gains in employment in Pennsylvania.

[53] See Appendix Figure 3

The real harm to Pennsylvania would not be in employment, as shown in the above shift share and employment quotient analysis, but in the loss of taxable oil and gas industry revenues that would be significantly affected by the loss in fracking density. Pennsylvania's use of "impact fees" in lieu of the conventional severance tax is unique in its direct imposition on the oil and gas industry per well[54], the proceeds of which are then distributed largely towards the local capital budget. Such legislative action is odd in that the impact fee may encourage companies to focus less on well density and focus more on well capacity, while simultaneously encouraging municipalities (or outright prohibiting bans) to reduce local regulations on fracking in order to capture more income from the proliferation of unconventional wells.

VI. SUMMARY AND RECOMMENDATIONS

The analysis of potential standardized setback distances from groundwater sources showed that there would not be more than a 10% reduction in existing quantity of hydraulically fractured wells up to a ¼ mile radius for Pennsylvania and up to 1 mile for Texas. This means that if either state decided to enforce a larger uniform setback distance from groundwater or public drinking wells than what currently exists in both states, their decision would not constitute a "de-facto ban" on fracking as opponents claim. Though this observation is dependent on the geographical features unique to each county and state, the results of this study suggests that it would be to the public benefit for municipalities and local governments with high unconventional well density to undertake a survey of the conditions surrounding their groundwater wells and drinking water sources.

[54] StateImpact Pennsylvania. "Severance Tax." Accessed March 25, 2020. https://stateimpact.npr.org/pennsylvania/tag/severance-tax/.

In most cases, the social costs of health impacts and access to clean air and water are not necessarily offset by the tax revenues that municipalities stand to gain; conversely, stricter regulations that may discourage fracking in counties are not implicitly bad for the local economy. It can be said that in states where a setback would effectively constitute a "ban" on fracking, that there is not enough oil potential in the state to justify the infrastructure costs and social costs anyway. For example, we see that in the case of Illinois, which has to date, 2 applications for fracking permits since the lift of its fracking moratorium in 2015, the exclusion of the wells due to zoning setbacks will either be negligible to the overall economy, or can be offset by special zoning variances. Two wells cannot support an entire economy, and it would be remiss to upend the right of local municipal control for the sake of potential future wells. The use of zoning and setbacks are especially salient now as tools to combat the shifting of regulatory power from local to state; especially in Texas where the State Supreme court affirmed the state's mandate to prohibit county level fracking bans, setbacks can be more effectively leverage to mitigate the externalities of fracking if municipalities take the steps to quantify the economic and social costs.

From a methodological standpoint, an unexpected outcome of using the Getis Ord Gi* hotspot analysis on instances of fracked wells in US counties was that the hotspot analysis may be a useful tool for pinpointing the socio-relational confluence of local regulatory attitudes and as to determine sentimental clusters of similar public policy. This study shows that the clustering of well locations may be indicative of not only a geological advantage (i.e. where oil and gas reserves are), but a regulatory advantage as well, as none of the counties in Texas with significant unconventional well hotspots had existing zoning or setback codes regulating oil and gas drilling, and those counties tended to be in close proximity to one another. This means that in cases where documentation for municipal regulations and local codes are not centralized, the Getis Ord Gi* hotspot analysis could be an effective tool in identifying where similar regulations tend to occur based on a clustering of the regulated (or unregulated) thing in question[55]. By using the hotspot analysis, we can also get a feel for the degree of influence one county has on its surrounding counties, which is important in understanding the power of public opinion and social pressure in determining whether or not a controversial practice is strictly regulated.

The economic impacts of having more restrictive oil and gas drilling covenants does not seem to play a significant part in promoting the overall employment figures of a state, and it is not recommended to tout potential employment gains as a social benefit for lax fracking regulations. At a more macro level, the economic impacts of a 10% decrease in oil and gas fracking in Pennsylvania due to a 1 mile state mandated setback would not significantly affect employment if a simplistic proportional reduction is made[56]. The delta in employment in New York shows an increase in shares in the NAICS 21 industry even after the imposition of a total fracking ban; because coal mining is not a major viable industry in New York, we can assume any growth within the sector can largely be attributed to oil and gas. From the models conducted in this study, we can assume that the relationship between fracked well count, well density, and employment may not even be linear if it is significant at all; it is inconclusive whether or not a reduction in total number of oil and gas wells would reduce employment numbers significantly in Pennsylvania. This is especially unlikely due to the small percentage of shares the oil and gas extraction industry has in total employment within the state, and

[55] For example, using hotspot analysis to understand the regulatory landscape of solar panels by finding hotspots of solar panels. Areas with more tax incentives for clean energy or tighter restrictions on power plants might encourage more solar panels

[56] 10% of 28,111 employed would equal a loss of 281 jobs or 0.004% of total PA employment

even more so because industry is self contained to only a select few counties across the state. This conclusion might not apply to states where oil and gas well exist in many or most of their counties.

The results of this study's analysis closely mirror prior studies on the Marcellus shale region, which also concluded no significant impacts to employment or incomes[57]. The data shows that the influence of US crude oil and gas prices to be stronger predictor of changes in NAICS level employment than potential regulatory impacts; recent drastical market fluctuations in crude oil prices due to the emergence of Covid-19 virus once again underscore the sheer volatility of the energy market and its dependency on global events[58]. The 2020 crash in crude oil prices overnight immediately led to the dismantling of rigs across the states, exemplifying one in many ways of how overexposure and over reliance on private oil and gas extraction to support the economy is not recommended for states in the US. While revenues from severance taxes and impact fees may pose as attractive temporary options to fill much needed capital budgets, policy makers should keep in mind that oil and gas are expendable resources, and that the advancements made in extraction efficiencies create self-defeating processes which ultimately culminates in the depletion of the shale basins, and a zeroing of both land values and tax revenues. However, the social and environmental costs of increased fracking density may not be offset by the short term gains, as the harms may linger for generations.

Going forward, my recommendations for municipalities and policy makers across states and regions with significant oil and gas extraction potential to consider planning as a tool to achieve a socially equitable balance between capturing energy industry revenues and mitigating harmful

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[57] Paredes, Dusan, Timothy Komarek, and Scott Loveridge. "Income and Employment Effects of Shale Gas Extraction Windfalls: Evidence from the Marcellus Region." *Energy Economics* 47 (January 1, 2015): 112–20. https://doi.org/10.1016/j.eneco.2014.09.025.
[58] OilPrice.com. "The Most Destructive Oil Price Crash In History?" Accessed March 25, 2020. https://oilprice.com/Energy/Energy-General/Is-This-The-Most-Destructive-Oil-Price-Crash-In-History.html.

environmental externalities. Contrary to what the oil and gas industry corporations or supporters may claim, the positive impacts modeled by input/out models like IMPLAN are too rigid and self-fulfilling in their output, which cannot account for changing market dynamics, technological advancements over time, nor social costs and benefits. We see from analysis of the 1 mile and 2 mile buffers that extension of existing setbacks would not significantly diminish the extraction ability of existing and future wells in certain states. In the case of Pennsylvania, which has been suffering from the economic blowback of a declining coal industry, lessons should be learned from its own history that reliance on nonrenewable resources for capital income is not sustainable long term. Rather, shifting its labor force and industry development to other dominant or rising sectors such as transportation and warehousing, and manufacturing sectors will allow for a healthier state economy for future generations.

The strong fit of the models measuring health outcomes is alarming in what the results imply. While the positive relationship between proximity of unconventional wells to public drinking wells seem counterintuitive, the results point to a compounding of negative externalities that disproportionately impact minority communities. We saw that despite having higher incomes, communities with less access to local sources of public drinking water tend to be located in drought prone areas of Texas, and have a high proportion of nonwhite population. These same counties also bear the burden of high fracking density, water usage for fracking, and poor health. Municipalities should conduct further studies to drought prone areas and exercise oversight into how local water sources are used, and if the transport of nonlocal water sources have significant impact on local health outcomes. Though increasing setbacks between unconventional wells and public drinking wells will generally not have much effect in those communities due to lack of public drinking wells, base setbacks should extend from residential areas. Alternatively, those counties should consider zoning-based fracking control, where fracking and drilling is contained to industrial zones with a minimum setback from residential buildings and public facilities. Due to a lack of centralized zoning data, this study could not analyze the effect of minimum setbacks from residential buildings, but municipalities should take it upon themselves to conduct this research, especially in counties with over 1000 operational unconventional wells.

VII. CONCLUSION

While this study focused on a comparative analysis of the Texas and Pennsylvania oil and gas industry, the observations can be replicated for all states with existing unconventional wells. As more and more municipalities rise to challenge state hegemony on fracking using zoning as their primary line of defense, a raw look at what the data can show about the impacts of increasing fracking limits or drilling setbacks can present a more realistic look at what numbers are economically viable than high-level input/output which may exaggerate benefits at a larger, regional level. No one will contest that an expansion of a certain industry will provide more job opportunities and taxable revenue, but the net benefits of public support for private ventures must be measured not only through the fiscal lens, but through the social lens as well. As climate change and energy issues shove themselves to the forefront of global policy decisions, local communities and smaller municipalities should be empowered with the methods familiar to them to make the arguments that are in the best interest of their populace-- zoning and planning at the helm. At least for Texas and Pennsylvnia, this study shows that even a 2 mile setback from drinking wells would not constitute an effective "ban" on fracking. Though the reduction may be greater if setbacks were applied to residential plots, it would still not completely eliminate the industry's ability to extract value. Where states do not have the knowledge, interest, nor sense of urgency as municipalities do in fracking matters, local communities should empower themselves with knowledge that there can be a solution where fracking and reduction of social harms reach compromise.

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APPENDIX

TABLE 1
Shift Share Analysis - New York

	NY INDUSTRY BY OCCUPATION			NATIONAL INDUSTRY BY OCCUPATION			SHIFT SHARE ANALYSIS			
Industry	**2012 Total**	**2017 Total**	**% Change**	**2012 Total**	**2017 Total**	**%Change**	**NS**	**IM**	**RS**	**SS**
Agriculture, forestry, fishing and hunting, and mining:	51,554	52,520	2%	2,830,729	2,637,326	-7%	55778.4	-7746.7	4488.31	52520
Agriculture, forestry, fishing and hunting	45,229	45,990	2%	1,946,917	1,906,427	-2%	48935.2	-4646.8	1701.63	45990
Mining, quarrying, and oil and gas extraction	6,325	6,530	3%	883,812	730,899	-17%	6843.3	-1612.6	1299.32	6530
Construction	511,823	551,537	8%	8,802,312	10,292,425	17%	553762.8	44705.0	-46930.75	551537
Manufacturing	614,140	584,904	-5%	14,988,864	15,631,115	4%	664463.8	-24008.8	-55551.00	584904
Wholesale trade	223,605	221,498	-1%	3,785,841	3,984,192	5%	241927.6	-6607.3	-13822.30	221498
Retail trade	1,014,676	989,478	-2%	16,639,780	17,342,338	4%	1097820.6	-40303.3	-68039.24	989478
Transportation and warehousing, and utilities:	453,119	527,257	16%	7,020,960	8,343,526	19%	490248.5	48226.4	-11217.82	527257
Information	256,407	273,633	7%	2,975,482	3,135,019	5%	277417.5	-7262.7	3478.18	273633
Finance and insurance, and real estate and rental and leasing:	726,950	770,444	6%	9,414,894	10,227,159	9%	786517.7	3149.5	-19223.23	770444
Professional, scientific, and management, and administrative and waste management services:	1,021,447	1,163,020	14%	15,591,744	17,865,131	15%	1105146.4	65234.8	-7361.23	1163020
Educational services, and health care and social assistance:	2,486,435	2,668,285	7%	33,113,097	35,805,182	8%	2690178.4	-1597.0	-20296.43	2668285
Arts, entertainment, and recreation, and accommodation and food services:	854,118	912,225	7%	13,697,912	15,071,444	10%	924106.1	15656.9	-27538.05	912225
Other services, except public administration	458,288	487,740	6%	7,118,937	7,596,464	7%	495841.0	-6811.8	-1289.23	487740
Public administration	427,204	431,896	1%	6,941,135	7,127,010	3%	462209.9	-23565.9	-6747.99	431896
Total	9,151,320	9,686,957	6%	145,752,416	157,695,657	8%				

TABLE 2
Shift Share Analysis - Pennsylvania

	PA INDUSTRY BY OCCUPATION			NATIONAL INDUSTRY BY OCCUPATION			SHIFT SHARE ANALYSIS			
Industry	**2012 Total**	**2017 Total**	**% Change**	**2012 Total**	**2017 Total**	**%Change**	**NS**	**IM**	**RS**	**SS**
Agriculture, forestry, fishing and hunting, and mining:	86,233	75,446	-13%	2,830,729	2,637,326	-7%	93299.1	-12957.8	-4895.33	75446
Agriculture, forestry, fishing and hunting	55,794	51,964	-7%	1,946,917	1,906,427	-2%	60365.9	-5732.2	-2669.65	51964
Mining, quarrying, and oil and gas extraction	30,439	23,482	-23%	883,812	730,899	-17%	32933.2	-7760.6	-1690.59	23482
Construction	332,177	364,421	10%	8,802,312	10,292,425	17%	359396.2	29013.9	-23989.10	364421
Manufacturing	728,625	716,057	-2%	14,988,864	15,631,115	4%	788330.0	-28484.5	-43788.52	716057
Wholesale trade	164,596	166,981	1%	3,785,841	3,984,192	5%	178083.3	-4863.7	-6238.65	166981
Retail trade	702,787	693,173	-1%	16,639,780	17,342,338	4%	760374.8	-27915.0	-39286.79	693173
Transportation and warehousing, and utilities:	298,932	364,128	22%	7,020,960	8,343,526	19%	323427.1	31815.9	8885.00	364128
Information	100,921	100,469	0%	2,975,482	3,135,019	5%	109190.7	-2858.6	-5863.10	100469
Finance and insurance, and real estate and rental and leasing:	374,736	400,028	7%	9,414,894	10,227,159	9%	405442.6	1623.5	-7038.15	400028
Professional, scientific, and management, and administrative and waste management services:	577,210	659,803	14%	15,591,744	17,865,131	15%	624507.7	36863.6	-1568.32	659803
Educational services, and health care and social assistance:	1,551,286	1,592,154	3%	33,113,097	35,805,182	8%	1678401.4	-996.3	-85251.09	1592154
Arts, entertainment, and recreation, and accommodation and food services:	493,275	504,467	2%	13,697,912	15,071,444	10%	533694.9	9042.3	-38270.21	504467
Other services, except public administration	276,154	292,354	6%	7,118,937	7,596,464	7%	298782.6	-4104.6	-2323.97	292354
Public administration	244,345	243,662	0%	6,941,135	7,127,010	3%	264367.1	-13478.9	-7226.26	243662
Total	6,017,510	6,248,589	4%	145,752,416	157,695,657	8%				

TABLE 3
Shift Share Analysis - Texas

	TX INDUSTRY BY OCCUPATION			NATIONAL INDUSTRY BY OCCUPATION			SHIFT SHARE ANALYSIS			
Industry	**2012 Total**	**2017 Total**	**% Change**	**2012 Total**	**2017 Total**	**%Change**	**NS**	**IM**	**RS**	**SS**
Agriculture, forestry, fishing and hunting, and mining:	394,429	374,042	-5%	2,830,729	2,637,326	-7%	426749.3	-59268.7	6561.45	374042
Agriculture, forestry, fishing and hunting	107,486	111,040	3%	1,946,917	1,906,427	-2%	116293.6	-11043.0	5789.38	111040
Mining, quarrying, and oil and gas extraction	286,943	263,002	-8%	883,812	730,899	-17%	310455.7	-73158.2	25704.53	263002
Construction	1,188,835	1,145,046	-4%	8,802,312	10,292,425	17%	1286250.5	103838.3	-245042.77	1145046
Manufacturing	1,126,931	1,122,565	0%	14,988,864	15,631,115	4%	1219274.0	-44055.6	-52653.35	1122565
Wholesale trade	359,631	378,164	5%	3,785,841	3,984,192	5%	389099.9	-10626.8	-309.09	378164
Retail trade	1,530,829	1,510,013	-1%	16,639,780	17,342,338	4%	1656268.2	-60805.1	-85450.04	1510013
Transportation and warehousing, and utilities:	821,118	775,281	-6%	7,020,960	8,343,526	19%	888402.0	87393.2	-200514.24	775281
Information	217,728	229,427	5%	2,975,482	3,135,019	5%	235569.1	-6167.1	25.04	229427
Finance and insurance, and real estate and rental and leasing:	889,961	880,815	-1%	9,414,894	10,227,159	9%	962886.2	3855.8	-85926.91	880815
Professional, scientific, and management, and administrative and waste management services:	1,566,465	1,500,132	-4%	15,591,744	17,865,131	15%	1694824.2	100042.5	-294734.72	1500132
Educational services, and health care and social assistance:	2,902,134	2,846,479	-2%	33,113,097	35,805,182	8%	3139940.6	-1864.0	-291597.64	2846479
Arts, entertainment, and recreation, and accommodation and food services:	1,263,471	1,232,846	-2%	13,697,912	15,071,444	10%	1367002.3	23160.8	-157317.14	1232846
Other services, except public administration	697,821	680,544	-2%	7,118,937	7,596,464	7%	755001.8	-10372.1	-64085.73	680544
Public administration	531,815	526,537	-1%	6,941,135	7,127,010	3%	575393.0	-29336.6	-19519.35	526537
Total	13,885,597	13,575,933	-2%	145,752,416	157,695,657	8%				

TABLE 4
Shift Share Analysis - Illinois

	IL INDUSTRY BY OCCUPATION			NATIONAL INDUSTRY BY OCCUPATION			SHIFT SHARE ANALYSIS			
Industry	**2012 Total**	**2017 Total**	**% Change**	**2012 Total**	**2017 Total**	**%Change**	**NS**	**IM**	**RS**	**SS**
Agriculture, forestry, fishing and hunting, and mining:	63,463	65,582	3%	2,830,729	2,637,326	-7%	68663.3	-9536.2	6454.96	65582
Agriculture, forestry, fishing and hunting	52,210	53,616	3%	1,946,917	1,906,427	-2%	56488.2	-5364.0	2491.81	53616
Mining, quarrying, and oil and gas extraction	11,253	11,966	6%	883,812	730,899	-17%	12175.1	-2869.0	2659.94	11966
Construction	302,342	332,236	10%	8,802,312	10,292,425	17%	327116.5	26407.9	-21288.43	332236
Manufacturing	764,880	748,123	-2%	14,988,864	15,631,115	4%	827555.8	-29901.8	-49530.99	748123
Wholesale trade	174,636	187,470	7%	3,785,841	3,984,192	5%	188946.0	-5160.3	3684.32	187470
Retail trade	662,225	652,301	-1%	16,639,780	17,342,338	4%	716489.0	-26303.8	-37884.19	652301
Transportation and warehousing, and utilities:	359,136	406,125	13%	7,020,960	8,343,526	19%	388564.3	38223.6	-20662.87	406125
Information	124,233	117,319	-6%	2,975,482	3,135,019	5%	134412.9	-3518.9	-13575.03	117319
Finance and insurance, and real estate and rental and leasing:	441,793	454,429	3%	9,414,894	10,227,159	9%	477994.4	1914.1	-25479.46	454429
Professional, scientific, and management, and administrative and waste management services:	671,162	725,968	8%	15,591,744	17,865,131	15%	726158.3	42863.8	-43054.19	725968
Educational services, and health care and social assistance:	1,385,306	1,428,355	3%	33,113,097	35,805,182	8%	1498820.7	-889.7	-69575.97	1428355
Arts, entertainment, and recreation, and accommodation and food services:	548,478	582,931	6%	13,697,912	15,071,444	10%	593421.4	10054.2	-20544.59	582931
Other services, except public administration	295,714	304,770	3%	7,118,937	7,596,464	7%	319945.4	-4395.4	-10780.03	304770
Public administration	237,223	229,245	-3%	6,941,135	7,127,010	3%	256661.5	-13086.0	-14330.54	229245
Total	6,094,054	6,300,436	3%	145,752,416	157,695,657	8%				

TABLE 5 2012 Employment Quotient NY/PA					
2012	EMPLOYMENT		SHARE		RATIO OF SHARES
Industry	**NY**	**PA**	**NY**	**PA**	**NY/PA**
Agriculture, forestry, fishing and hunting, and mining:	51,554	86,233	0.56%	1.43%	0.39
Agriculture, forestry, fishing and hunting	45,229	55,794	0.49%	0.93%	0.53
Mining, quarrying, and oil and gas extraction	6,325	30,439	0.07%	0.51%	0.14
Construction	511,823	332,177	5.59%	5.52%	1.01
Manufacturing	614,140	728,625	6.71%	12.11%	0.55
Wholesale trade	223,605	164,596	2.44%	2.74%	0.89
Retail trade	1,014,676	702,787	11.09%	11.68%	0.95
Transportation and warehousing, and utilities:	453,119	298,932	4.95%	4.97%	1.00
Information	256,407	100,921	2.80%	1.68%	1.67
Finance and insurance, and real estate and rental and leasing:	726,950	374,736	7.94%	6.23%	1.28
Professional, scientific, and management, and administrative and waste management services:	1,021,447	577,210	11.16%	9.59%	1.16
Educational services, and health care and social assistance:	2,486,435	1,551,286	27.17%	25.78%	1.05
Arts, entertainment, and recreation, and accommodation and food services:	854,118	493,275	9.33%	8.20%	1.14
Other services, except public administration	458,288	276,154	5.01%	4.59%	1.09
Public administration	427,204	244,345	4.67%	4.06%	1.15
Total	9,151,320	6,017,510	100.00%	100.00%	

APP. FIGURE 1

```
Call:
lm(formula = DeltaWell ~ DeltaMedianIncome + Delta_PercentNonWhite +
    Interact_IncomeRace, data = dfDelta)

Residuals:
    Min      1Q  Median      3Q     Max
 -435.2   -84.9   -83.6   -71.9 10724.9

Coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)             84.048     11.649   7.215  8.3e-13 ***
DeltaMedianIncome       42.534     42.800   0.994    0.320
Delta_PercentNonWhite    4.638     20.807   0.223    0.824
Interact_IncomeRace    -75.364     74.327  -1.014    0.311
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 445.2 on 1602 degrees of freedom
Multiple R-squared:  0.001119,  Adjusted R-squared:  -0.0007516
F-statistic: 0.5982 on 3 and 1602 DF,  p-value: 0.6162
```

APP. FIGURE 2

```
Call:
lm(formula = DeltaMedianIncome ~ DeltaWell, data = dfDelta)

Residuals:
     Min       1Q   Median       3Q      Max
-0.90162 -0.07925  0.01308  0.01308  2.73895

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.308e-02  6.962e-03  -1.878   0.0605 .
DeltaWell    1.073e-05  1.537e-05   0.698   0.4854
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.2741 on 1604 degrees of freedom
Multiple R-squared:  0.0003035, Adjusted R-squared:  -0.0003197
F-statistic: 0.487 on 1 and 1604 DF,  p-value: 0.4854
```

APP. FIGURE 3

```
Call:
lm(formula = PercentExtract ~ WellCount + WellDensit, data = dfPAWork2017)

Residuals:
      Min        1Q    Median        3Q       Max
-0.027844 -0.013789  0.003402  0.010575  0.059133

Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)  6.096e-02  3.978e-03  15.325 3.82e-15 ***
WellCount   -8.348e-05  3.917e-05  -2.131   0.0420 *
WellDensit   5.310e+01  1.946e+01   2.728   0.0109 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.01843 on 28 degrees of freedom
  (36 observations deleted due to missingness)
Multiple R-squared:  0.2731,    Adjusted R-squared:  0.2211
F-statistic: 5.259 on 2 and 28 DF,  p-value: 0.01151
```